THE DISTRIBUTION OF SUSPENDED PARTICULATE MATTER OFF THE CALIFORNIA COAST FROM SAN FRANCISCO BAY TO CAPE SAN MARTÍN

Lawrence Florian Diddlemeyer

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE DISTRIBUTION OF SUSPENDED
PARTICULATE MATTER OFF THE
CALIFORNIA COAST FROM
SAN FRANCISCO BAY TO CAPE SAN MARTÍN

by

Lawrence Florian Diddlemeyer

December 1975

Thesis Advisor: S.P. Tucker

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The distribution of suspended particulate matter in the 1.4 to 27.9 μ range based on data gathered during four cruises off the California coast from San Francisco Bay to Cape San Martin is presented by means of isometric drawings as well as more conventional graphs.

It was observed that pycnoclines set up particle "traps". In areas where a deep mixed layer existed particle concentrations were randomly distributed in the layer. Counts of larger sized particles decreased with

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) depth; those for smaller particles appeared to remain about constant throughout the water column.

Particle sizes and distributions reflected bottom topography and water depth. Shallow water stations exhibited higher particle concentrations, while stations over Monterey Canyon showed depressed counts over the entire size range. In localized upwelling areas higher concentrations around the areas' peripheries than in their centers were found. Data were assumed to follow a distribution of the form $M_i=K(1-2^{-C/3})D_i^{-C}$, where M_i is count in Coulter counter channel i (i=0,1,...,13), K and C are constants, and $D_i=27.9\times 2^{-i/3}$ is diameter in μ of channel i. C values generally occurred in the 2.4 to 3.1 range, but significant deviations were noted during upwelling. K values often fell in the 50 to 300 x 10^3 particles/ml range, but extremely high values were noted for the Davidson Current period. Phytoplankton blooms appeared to be responsible for "knees" or "peaks" in many of the size distributions.

The Distribution of Suspended
Particulate Matter off the
California Coast from
San Francisco Bay to Cape San Martín

by

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B.S., United States Naval Academy, 1969

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FORWARD

The present work, the first of a series of reports concerned with the distribution of suspended particulates in the 1.5 - 35 μ size range in California coastal waters, is part of a broader continuing study of the factors influencing the optical properties of this region. Detailed cruise data for all the oceanographic stations of the four cruises which form the basis of this thesis are reported in NPS Technical Report, NPS-58TX75122, December 1975. Support for this work has come from several sources including Code 480 of the Office of Naval Research, the Naval Air Systems Command, and the NPS Research Foundation Program funded by the Chief of Naval Research.

November 1975

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ABSTRACT

The distribution of suspended particulate matter in the 1.4 to 27.9μ range based on data gathered during four cruises off the California coast from San Francisco to Cape San Martin is presented by means of iso-metric drawings as well as more conventional graphs.

It was observed that pycnoclines set up particle "traps." In areas where a deep mixed layer existed particle concentrations were randomly distributed in the layer. Counts of larger sized particles decreased with depth; those for smaller particles appeared to remain about constant throughout the water column.

Particle sizes and distributions reflected bottom topography and water depth. Shallow water stations exhibited higher particle concentrations, while stations over Monterey Canyon showed depressed counts over the entire size range. In localized upwelling areas higher concentrations around the areas' peripheries than in their centers were found. Data were assumed to follow a distribution of the form $M_i = K(1-2^{-C/3})D_i^{-C}$ where M_i = count in Coulter counter channel i (i = 0,1,...,13), K and C are constants, and $D_i = 27.9 \times 2^{-i/3}$ is the diameter in μ of channel i. C values generally occurred in the 2.4 to 3.1 range, but significant deviations were noted during upwelling. K values often fell in the 50 to 300 x 10^3 particles/ml range, but extremely high values were noted for the Davidson Current period. Phytoplankton blooms appeared to be responsible for "knees" or "peaks" in many of the size distributions.

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To my father

Frank J. Diddlemeyer

I. INTRODUCTION

A. BACKGROUND

In the past two decades oceanography has become one of the fastest growing sciences. Military, economic, and more recently environmental problems have indicated that a need still exists for much more data and detailed studies of the various properties of the sea. Because all life in the sea is directly or indirectly affected by the occurrence and propagation of light in sea water, optical oceanography is a field which can make a significant contribution to our knowledge of the oceans. The distribution and density of particulate matter (both organic and inorganic) are major factors affecting the transmission of light through seawater. Particles, and their ability to absorb, attenuate, and scatter light control the depth of the euphotic zone. This zone and the availability of nutrients is the basis upon which the entire food chain of the oceans is established and maintained.

Areas of upwelling are perhaps the most important regions in the ocean; this is especially true with regard to fisheries. These areas of colder, nutrient-rich waters produce approximately one-half of the world's fish supply although their surface area only accounts for about one-tenth of one percent of the total surface area of the oceans [14]. Joseph [9] among others has noted that during upwelling high particle counts can be expected.

The distribution of particulate matter is also of prime importance as the controlling constituent of the characteristic optical signatures displayed by seawater samples. Such signatures are used to help in the identification of water masses and the establishment of their boundaries.

Although Sheldon and Parsons [15], Sheldon, Prakash and Sutcliff [17], Jerlov [8], and Bader [1] have completed several investigations on the distribution of particulate matter, the distribution patterns, especially in coastal regions, may be highly complex and variable under the influences of winds, currents, upwelling, topography and runoff. It is therefore appropriate to make further more detailed studies. Combinations of factors in a given area can produce "particle traps" that show themselves as patches in which there are heavy particle concentrations. Particle count contours and observations based on one-time samples from these areas may be misleading. It is also to be expected that areas which undergo definite "oceanic seasons" (e.g., along the California coast) would display different distributions at different times of the year.

The multi-channel Coulter counter, which allows shipboard analysis of samples within a very short time interval, has contributed significantly to the development of a large data base for distribution studies. Ultra filtration and weighting procedures also exist which make it possible to determine particulate concentrations, size distributions and total counts, but these methods are very slow and tedious to use, or they give questionable results if the size distributions are to be used in models requiring the in situ size distribution such as those involving the scattering of light by seawater. In particle studies the direct counting method employed by the Coulter counter is also superior to the indirect methods, such as particle information extracted by analysis of the behavior of light in the sea or in a seawater sample which involves large numbers of particles. The major disadvantage of the Coulter counter is that particle sizes are determined from relative pulse heights and an absolute measure of particle size is not obtained. Furthermore the method has not yet been adapted to in situ measurement.

B. MARINE CLIMATOLOGY

Skogsberg [19] was the first to describe the oceanographic climate of Monterey Bay in terms of three major seasonal features, namely a cold water phase, a warm water phase, and a low thermal gradient phase. Bolin [3] later described and labeled these phases as the "Upwelling", the "Oceanic" and the "Davidson Current" periods.

The Upwelling Period is the longest of the three periods, usually beginning in late January and persisting until September. It is characterized by lower than normal surface temperatures (10 to 11 °C) with no clearly developed isotherms present. Upwelling off the West Coast is a direct result of the coastal winds. In the spring and summer months the atmospheric circulation is dominated by the North Pacific High which produces northerly winds parallel to the coast. According to Ekman's theory, these winds and the Coriolis effect cause the surface water to be transported 90° to the right of the wind and offshore. The result is a vertical advection of cold subsurface layers from depths suggested by Sverdrup [22] as great as 200 m replacing the surface water. The upwelled areas will normally have steeply ascending shallow isotherms and large horizontal temperature gradients. An increase in the surface salinity is also a normal consequence. Since density structure closely follows the temperature structure, the combined effect of the thermocline and halocline often produces a very strong pycnocline which can act as a particle trap. Upwelling is usually most intense in June and July.

In late summer the strong northerly winds tend to become more intermittent, and the coastal upwelling is interrupted. These interruptions give the cold dense surface waters a chance to sink and set up areas of convergence. An offshore flow of warm surface water from along the coast and an incoming flow of oceanic surface water replace the denser water, and a sharp thermocline is established in the first few meters. The Oceanic Period is characterized by surface temperatures greater than 13° C and a continuation of the strong vertical gradients established during the Upwelling Period. Another characteristic is the calm wind condition which marks the change between the northerly winds of the Upwelling Period and the southerly winds of the Davidson Current Period.

Following the Oceanic Period in November the wind completes its shift to become southerly, and upwelling has ceased. The onset of the Davidson Current Period is often noted by a sharp decline in surface temperature. Now the Coriolis effect causes a shoreward transport and low density surface water is piled up along the coast. This has two prime effects which are characteristic of the Davidson Current Period. First, as a result of the coastal concentration of less dense water, a current is set up which flows parallel to the coast and reinforces the wind driven current. Secondly, a sinking of the surface water occurs, and the thermocline weakens to relatively isothermal conditions to depths from 50 to 100 m. The Davidson Current Period usually lasts until February and is marked by the only sharp change in the oceanic climatic structure.

C. PREVIOUS LOCAL STUDIES

For the past seven years the Naval Postgraduate School has conducted a continuing series of oceanographic cruises off the central California coast. Summarized below are the findings concerned with the observed particulate matter distributions reported in a number of studies. All these studies deal with only the upper 100 m of water except Crews', which included depths to 250 m.

1. Yeske and Waer

Using a Model A Coulter counter, Yeske and Waer [23] conducted investigations of two stations within Monterey Bay during the Upwelling Period in July and August 1968. The two stations were occupied on alternate hours for one 24-hour period per week over a span of some 5 weeks. The main thrust of this study was to determine the effects of various oceanic parameters on beam transmittance and to study their spacial and temporal variability. A relatively high correlation between transmittance and particulate matter was noted, especially in the areas of pycnoclines and thermoclines where the highest concentrations of particles were found. It was also noted that particle size decreased with depth.

2. Labyak

Labyak [10] also used a Model A Coulter counter to conduct investigations at 79 stations between Monterey Bay and San Francisco Bay from 10 to 18 May 1969. This time frame is also part of the Upwelling Period, and Labyak's findings corresponded closely with those of Yeske and Waer.

3. Shepard

Another investigation during the Upwelling Period was conducted by Shepard [18] from 29 April to 5 May 1970. Analyzing 2 ml samples of seawater by means of a 15-channel Coulter counter along a track which ran from Monterey Bay north to San Francisco Bay, Shepard found total particle counts ranged from 5000 in very clear water to 200,000 in turbid water areas. It was also noted that the linear relationship (on a log-log plot of particle counts vs. diameter) for particle distribution in seawater as observed by Bader and Gordon [1,7] (the so-called Junge distribution) could be distorted in the 1.5 - 30 μ range by high productivity in the surface water layer.

4. Crews

Another Upwelling Period investigation was made by Crews [5] on a single station over the Monterey Submarine Canyon from 16 to 17 June 1971. As in the investigation of Yeske and Waer [23], the main aim was to collect beam transmission data and compare its temporal variability with that of other simultaneously collected data (i.e. phosphate, salinity, temperature and particle counts). In addition to comparing his data with those of Yeske and Waer [23], Labyak [10], and Shepard [18], Crews also made comparisons to the data collected by Baker [2] and Soluri [20] on cruises conducted during the Oceanic Period. It was found that the vertical distribution of particulate matter was dependent on both seasonal conditions and geographic location and that the largest concentrations of particles occurred in the upper 10 to 15 m of the water column.

D. OBJECTIVE

As was pointed out by Sheldon, Prakash and Sutcliffe [17], the general distribution of particulate matter suspended in the sea is fairly well-known and documented, but <u>detailed</u> information about distributions in specific areas and throughout the depth of the water column is quite scarce. Many investigations have been carried out in open ocean areas or along entire coasts in determining general distributions but these investigations ordinarily were characterized by single samples taken only once at widely spaced stations. The purpose of this research is twofold: first, to use a Coulter counter to determine particulate distributions for a large number of closely spaced ocean stations along the Central California coast during various oceanic seasons in such a manner that they may be compared with distributions determined elsewhere; and second, to display this data in a manner which will allow a study of the particle distributions by depth and along sections (i.e., along lines of stations) for these different seasons. To accomplish this, data from 178 stations collected over a 15-month period are analyzed here.

II. INSTRUMENTATION

A Model T Coulter counter was utilized in the analysis of the sea water samples. This instrument operates on the principle that a spherical particle passing through an electrical field that is maintained in an electrolyte will cause a change in the electrical properties of the field if the resistivity of the particle is different than that of the electrolyte. As the particle displaces its own volume of electrolyte, the current in the field is held constant and the change in resistivity is directly proportional to the change in voltage required to maintain the current. Through this method the height of the voltage pulse is linearly related to the particle volume. Sheldon and Parson [15] found this procedure can be extended to other than spherical particles with only a slight error, and the linear relation continues to apply as long as particle diameters are less than 40% and greater than about 2% of the aperture diameter. Utilizing a digital register, the counter records the height of each pulse in one of 15 discrete channels. A paper tape printout provides a record of the number of electronic counts in each size range. Particle size and volume are easily derived from this record. It must be recognized that the suspended particulates are not regularly shaped, and the sizes determined with the Coulter counter only furnish "signatures" which are representative of the approximate particle volumes.

The size of the aperture through which the electrolyte and particles are drawn is an important factor in determining the range of sizes which can be counted. The upper limit on particle diameter is controlled by the size of the aperture, while electrical noise effectively establishes a lower bound. With a 100 μ aperture and threshold settings corresponding to a logarithmic scale of particle diameters as suggested by Sheldon and Parsons, channels 13 to 0 range in size from approximately 1.3μ to 27μ respectively. Electrical noise in channel 14 prevented its use for the smaller diameters. The mean diameter in microns corresponding to each channel (indicated in parentheses) is listed below: 27.66 (0), 21.96 (1), 17.43 (2), 13.83 (3), 10.98 (4), 8.71 (5), 6.92 (6), 5.49 (7), 4.36 (8), 3.46 (9), 2.74 (10), 2.18 (11), 1.73 (12), and 1.37 (13).

Calibration of the counter was accomplished using divinylbenzene polystyrene latex spheres manufactured by Dow Corning Chemical Company. The calibration adjustment is set to give equal counts in two adjacent channels. By this method the peak in the particle size distribution of standard spheres lies at the division between the two channels and provides a size reference point.

An automatic timer was incorporated in the counter to allow a record of the counting time required for each 2 ml sample to be made. Comparison of these counting times provided an easy method to detect any obstruction of the orifice which may have invalidated the count.

A more comprehensive discussion of theory, operation and calibration of the Coulter counter is to be found in Sheldon and Parsons [15] and in the Model T Coulter manual.

It should also be noted that the availability of a high speed computer is absolutely essential in order to deal with the large amounts of data provided by the Coulter counter.

III. OBSERVATIONAL PROCEDURES

A. STATION LOCATIONS

Station data were collected from four cruises conducted by the Naval Postgraduate School's R/V ACANIA during the periods 27 to 31 October 1973, 14 to 17 January 1975, 15 to 18 April 1974 and 17 to 21 January 1975. The first two cruises covered the area from Monterey Bay north to San Francisco Bay. Approximate locations of the 118 stations occupied during these times are indicated in Figures 1 and 2. Stations in this northern coastal region were the same as those occupied by Shepard [18], Baker [2], Labyak [10] and Soluri [20]. Positions while on-station were determined every 15 minutes using Loran, radar or visual bearings; exact positions and time are indicated on each station's particulate data table [included in Reference 6].

The cruises of 15 to 18 April 1974 and 17 to 21 January 1975 covered the area from Monterey Bay south to Cape San Martín. These stations were selected to coincide with the standard station grid adopted for this region by the Naval Postgraduate School. Locations of 58 stations occupied in this southern coastal region are shown in Figures 3 and 4.

B. DATA COLLECTION

At each station a hydrographic cast was made, and water samples were collected in teflon-lined Nansen bottles. All

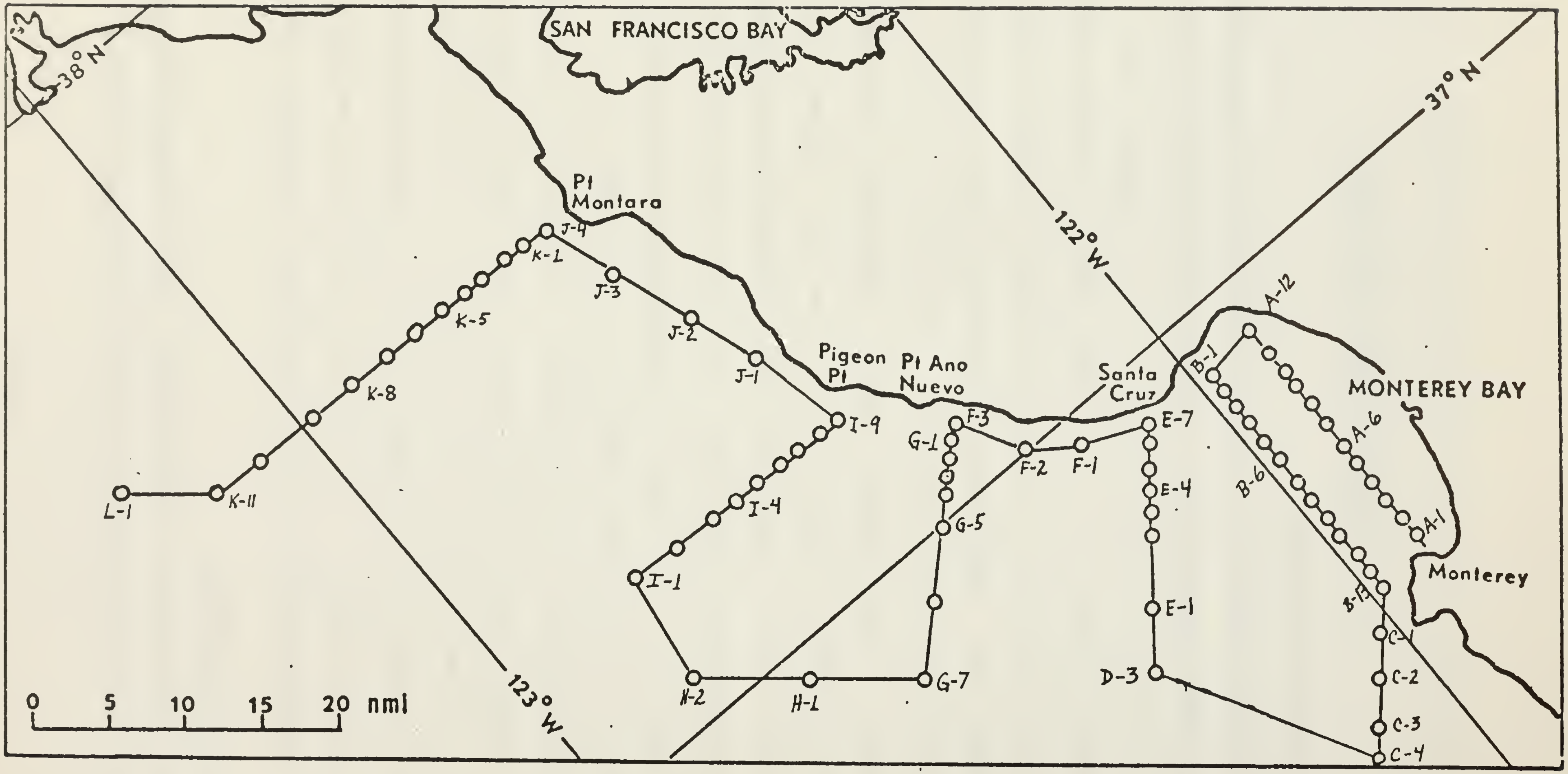

Figure 1. Approximate Station Locations, Cruise 27 to 31 October 1973

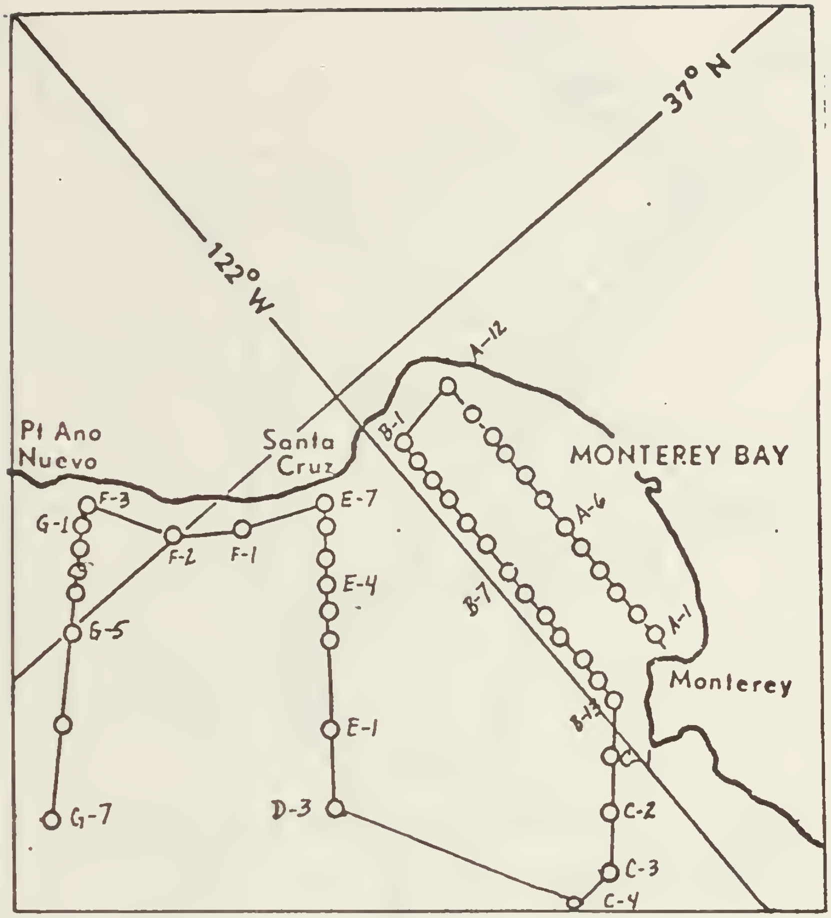

Figure 2. Approximate Station Locations, Cruise
14 to 17 January 1975

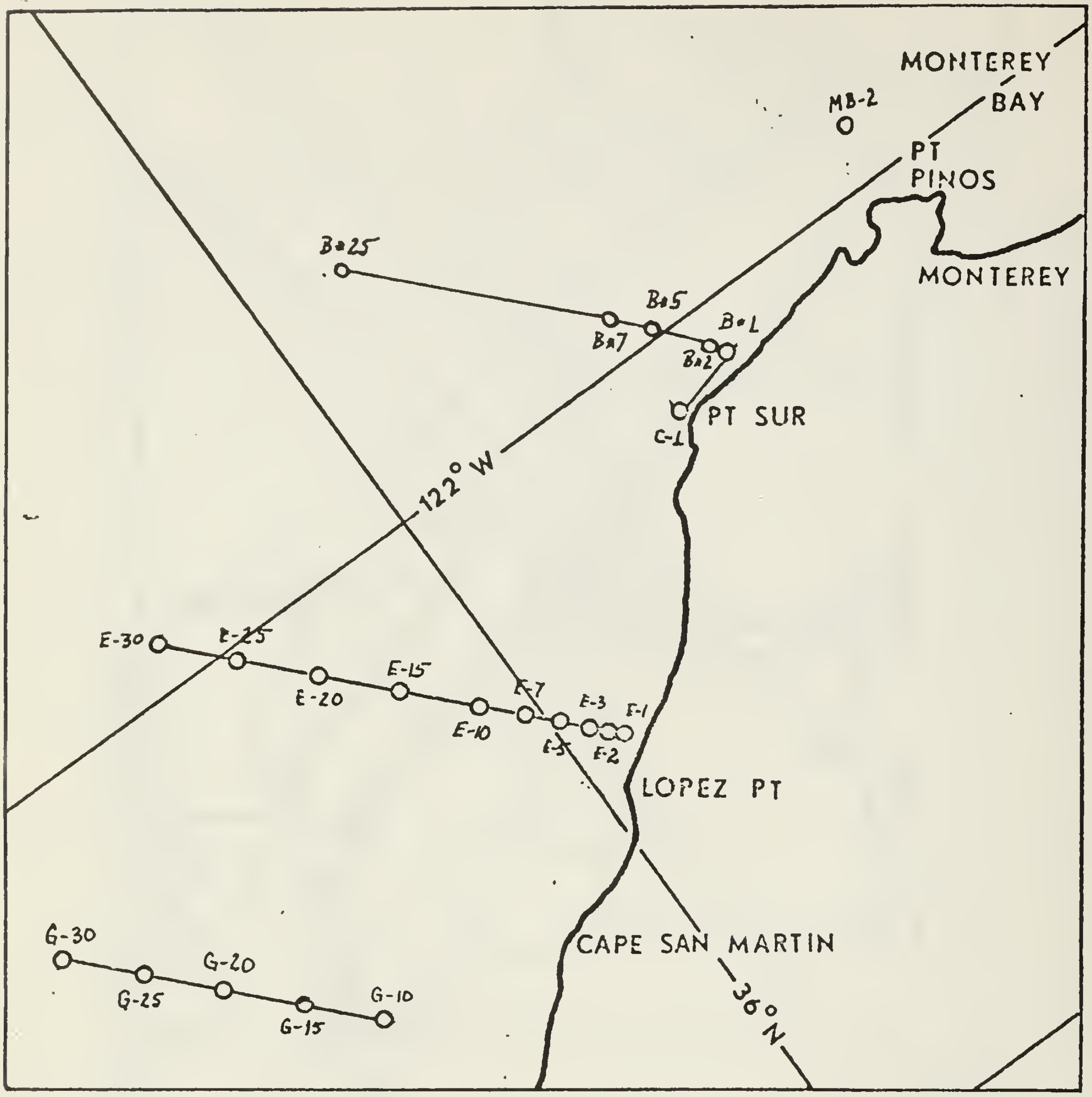

Figure 3. Approximate Station Locations, Cruise 15 to 18 April 1974

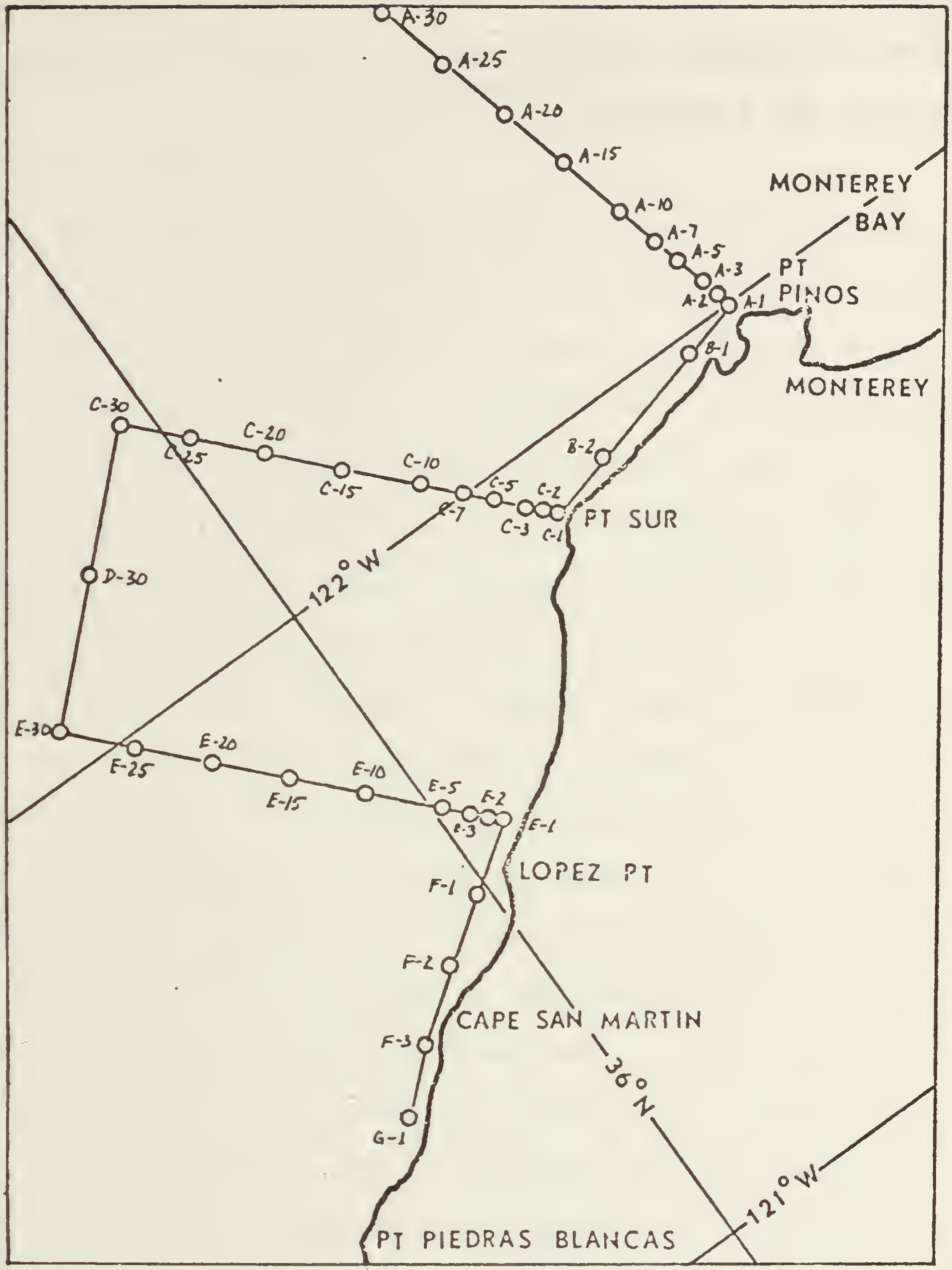

Figure 4. Approximate Station Locations, Cruise 17 to 21 January 1975

particulate matter samples were processed within 30 minutes after the samples were on board. STD and/or XBT casts were made at all stations.

IV. DATA ANALYSIS

A. INTRODUCTION

To depict the distribution of particulate matter in a water column with regard to depth, area, and oceanic season, data from four cruises along the central California coast were studied in some detail. Complete data tables and graphs for each cruise are presented in a technical report (NPS-58TX751101) available from the Naval Postgraduate School, Monterey, California, 93940. In order to concisely display the observations a station data table and five types of graphs are employed. (Sample computer programs for the station data and the graphing schemes are included in the Appendix.) To compare the present data with previous studies such as those of Gordon and Bader [7,1], a formula was developed from the general equation for a Junge distribution* that could be applied to any data from a particular channel number (i.e. particle diameter) of the Coulter counter. Solving this equation, values for C and K, the Junge distribution constants, could be computed for any station and depth. Comparison of graphs and numerical constants at a single station or area during different oceanic periods provides an insight to the "typical seasonal" particle

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*See page 40.

distributions that existed in this highly productive and complex coastal region.

B. DESCRIPTIVE TECHNIQUES

1. Station Data Tables

The station data table (two sample tables are included as Figure 5) gives the station number, time, date, and location of each observation. In addition the number of particles counted in each of the 13 channels used is indicated for each depth. Below the particle count the total volume in cubic microns occupied by that number of particles in each size range (channel) is indicated. The mean diameter in microns of the particles in each channel is also shown. All counts were made from a 2 ml seawater sample. On the second line from the bottom for each discrete depth, the total cumulative volume in cubic microns occupied by all particle sizes for that depth is displayed. The bottom line for each depth is an uncertainty factor (±). This factor, in cubic microns,applies to the total cumulative volume figure for each depth. The factor is computed by multiplying the square root of the particle count for each diameter (channel) times the volume occupied by one particle of this size. By summing these factors for each diameter over the entire size range the total uncertainty factor of the cumulative volume for each depth is obtained.

COULTER COUNTER DATA SHIP R/V ACANIA

STATION 8-5 , 0658 HRS PST, 36 DEG 50.4 MIN N, 122 DEG 00.0 MIN W, 28 OCT 73

PARTICLE DIAMETERS IN MICRONS, VOLUMES IN CUBIC MICRONS PER 2ML SEAWATER SAMPLE

PARTICLE COUNT / VOLUME PER COUNT

DIA	CH#	SAMPLE DEPTH IN METERS 0	5	10	15	20	30	40	50	60	70
27.66	0	8/88697	0/0	2/22174	5/55436	1/11087	0/0	0/0	1/11087	0/0	3/33261
21.96	1	8/44348	3/16630	4/22174	5/27718	6/33261	7/38805	3/16630	4/22174	1/5543	5/27718
17.43	2	20/55436	5/13859	4/11087	16/44348	8/22174	8/22174	7/19402	12/33261	7/19402	11/30489
13.83	3	58/80382	14/19402	14/19402	41/56821	27/37419	15/20788	16/22174	8/11087	24/33261	17/23560
10.98	4	86/59593	22/15244	22/15244	53/36726	36/24946	25/17323	20/13859	34/23560	40/27718	45/31182
8.71	5	181/62712	72/24946	67/23213	103/35686	66/22867	38/13166	38/13166	71/24599	85/29450	102/35340
6.92	6	461/79862	340/58903	301/52144	376/65138	241/41753	87/15071	71/12299	148/25639	229/39671	250/43309
5.49	7	898/77783	759/65743	680/58900	894/77437	532/46081	221/19142	174/15071	277/23993	690/59766	562/48679
4.36	8	1705/73842	1348/58381	1374/59507	1687/73062	1340/58034	470/20355	382/16544	561/24296	1109/48030	1083/46904
3.46	9	3272/70854	2594/56172	2729/59095	3055/66155	2598/56258	1213/26267	747/16176	1197/25920	1994/43179	2114/45778
2.74	10	5594/60589	4473/48430	4677/50639	5519/59756	4709/50986	2512/27198	1398/15138	2092/22650	3632/39324	3584/38805
2.18	11	6990/37821	5861/31729	5391/29185	6777/36688	5123/27718	3781/20469	2910/15340	3432/18579	6049/32747	5961/32270
1.73	12	11629/31477	9454/25590	8772/23738	10906/29515	8103/21933	6613/17900	3783/10239	5833/15788	9584/25942	9695/26242
1.37	13	49708/67275	46176/62495	40525/54847	47685/64537	34545/46753	26471/35826	15981/21628	18748/25373	27471/37179	28917/39136
TOTAL VOL (CH 0-13) IN 2ML SW		890691	497521	501349	728675	50126T	294484	202664	308006	441212	502673
UNCERT(±)		9226T	37135	53241	76446	55674	39379	32725	49178	36106	63425

COULTER COUNTER DATA SHIP R/V ACANIA

STATION 8-6 , 0800 HRS PST, 36 DEG 48.9 MIN N, 122 DEG 00.0 MIN W, 28 OCT T3

PARTICLE DIAMETERS IN MICRONS, VOLUMES IN CUBIC MICRONS PER 2ML SEAWATER SAMPLE

PARTICLE COUNT / VOLUME PER COUNT

DIA	CH#	SAMPLE DEPTH IN METERS 0	10	20	30	49	T3	97	145	194	290
27.66	0	0/0	1/11087	3/33261	3/33261	18/199569	0/0	0/0	0/0	0/0	2/22174
21.96	1	3/16630	3/16630	6/33261	0/0	46/255005	6/33261	2/11087	2/11087	1/5543	1/5543
17.43	2	6/16630	4/11087	6/16630	9/24946	79/218972	11/30489	4/11087	2/5543	5/13859	11/30489
13.83	3	7/9701	22/30489	26/36033	14/19402	175/242532	23/31875	20/27718	10/13859	11/15244	16/22174
10.98	4	3/2078	24/16630	19/13166	22/15244	221/153142	40/27718	24/16630	10/6929	18/12473	43/29796
8.T1	5	27/9354	29/10047	46/15937	39/13512	295/102210	87/30143	84/29103	33/11433	44/15244	109/37765
6.92	6	59/10221	87/15071	109/18882	57/9874	479/82980	185/32048	172/29796	70/12126	103/17843	262/45388
5.49	7	98/8488	152/13166	230/19922	160/13859	893/77350	368/31875	335/29017	140/12126	180/15591	545/47207
4.36	8	219/9484	315/13642	441/19099	390/16890	1673/72456	726/31442	630/27284	328/14205	372/16111	1087/47077
3.46	9	474/10264	581/12581	927/20073	1089/23571	3019/65375	1318/28540	1535/33238	670/14508	746/16154	2008/43482
2.T4	10	683/7395	1010/10935	1700/18406	2065/22358	5351/57937	2389/25866	2238/24239	1156/12516	1396/15114	3534/38263
2.18	11	1360/7362	1760/9528	3364/18211	3432/18579	9835/53243	3864/20918	3697/20014	1934/10470	2054/11119	5595/30289
1.73	12	3271/8854	4184/11327	6935/18769	8472/22935	18393/49786	6170/16701	5860/15862	3004/8131	3393/9184	8529/23086
1.37	13	21012/28438	25439/34427	37705/51030	39209/53066	58695/79438	20100/27203	17368/23506	11657/15776	12452/16852	24822/33594
TOTAL VOL (CH 0-13) IN 2ML SW		144899	216349	332680	284467	1T09995	3680T9	295521	148T09	180331	45632T
UNCERT(±)		2T185	42919	57941	43364	155218	44268	33124	25038	26876	52850

Figure 5. Sample Station Data Tables (from Reference 6).

2. Type 1 Graphs

The Type 1 graph depicts the logarithm (base 10) of the particle volume for a given depth and size as a function of the logarithm (base 10) of the particle diameter. A sample graph is shown in Figure 6. A separate curve is plotted and labelled for each depth increment. The straight horizontal lines indicated on most of these plots suggest the total particle volume for any given diameter (in a size range from 1μ to 30μ) is approximately constant. This agrees with the hypothesis presented by Sheldon, Prakash and Sutcliffe [17], i.e. total cumulative volume occupied by all particles in any size range from bacteria to whales is constant. Variations at the large end of the size scale result from too few particle counts for these sizes (zero counts occurred frequently at the larger diameters, i.e., channels 0 and 1) and probably do not indicate true distributions.

3. Type 2 Graphs

The Type 2 graph (shown in Figure 7) is similar to the Type 1 except that the logarithm (base 10) of the actual particle count for each depth and size, rather than the cumulative volume, is plotted as a function of the logarithm (base 10) of the particle diameter. Again each depth is labelled and corresponds to a specific curve. This log-log display also illustrates a straight line relationship which shows that as individual particle size increases the total number of particles of larger diameter must decrease in

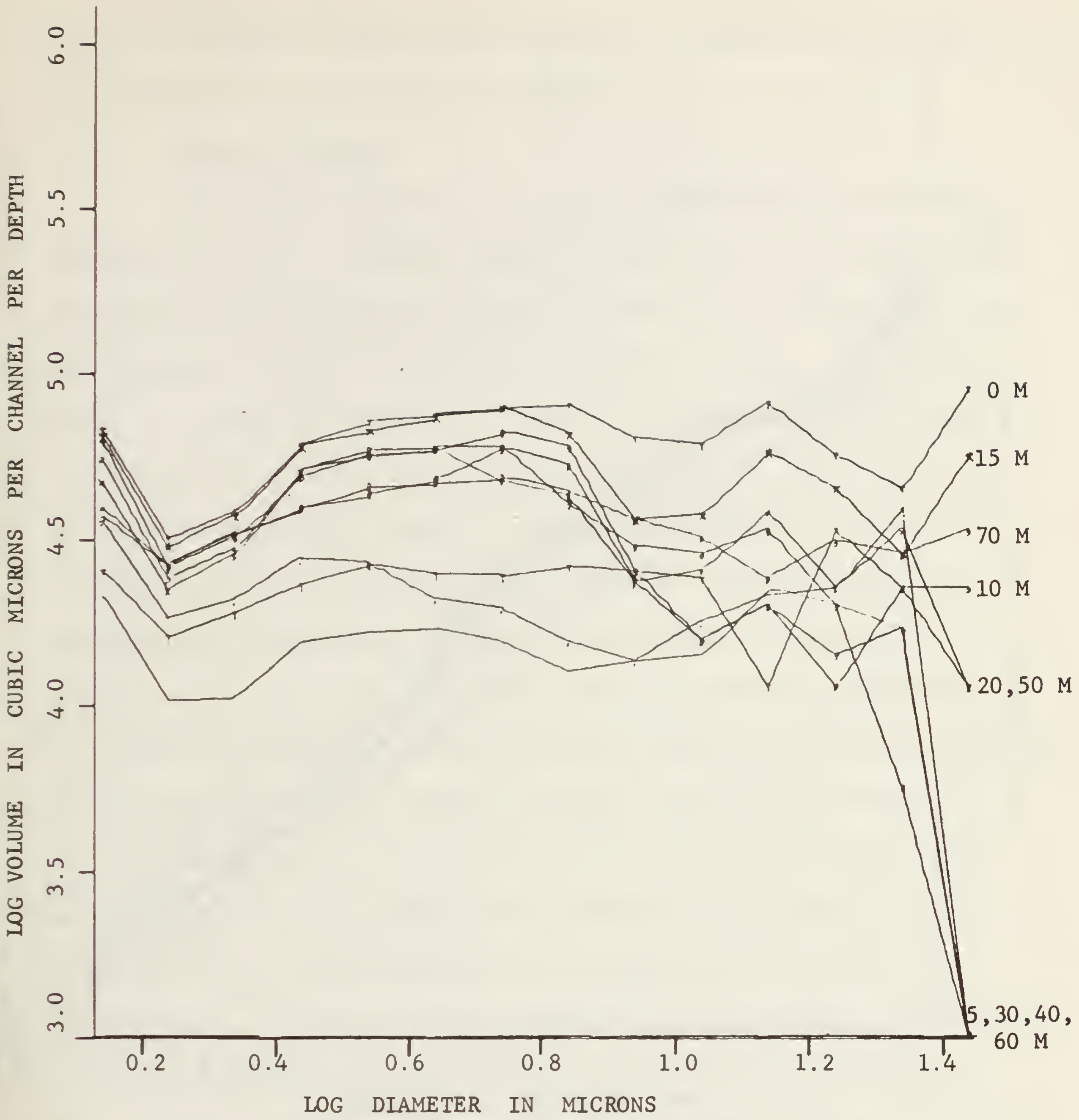

Figure 6. Type 1, Station B-5, Cruise 27 to 31 October 1973

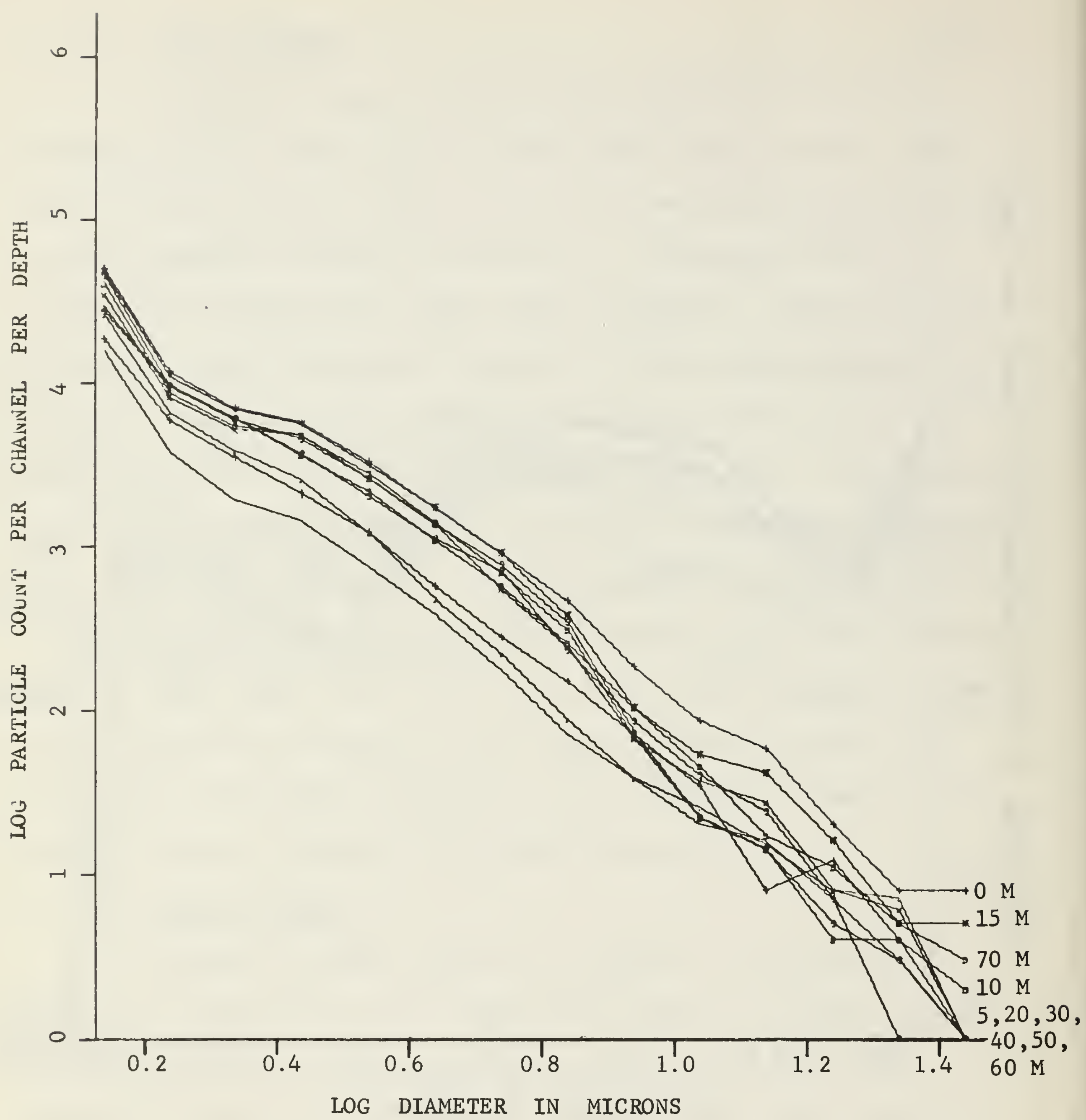

Figure 7. Type 2, Station B-5, Cruise 27 to 31 October 1973

order to maintain the total volume at a constant level as was indicated in the Type 1 graphs.

4. Type 3 Graphs

The Type 3 graph is a three-dimensional perspective drawing [13] for a single station depicting the logarithm of the number of particles counted (z-axis) as a function of the channel number (x-axis) and depth (y-axis). A sample graph is shown in Figure 8. Particle diameter is plotted increasing from the rear (channel 13) to the front (channel 0) of the graph and depth is plotted in meters with the surface value on the left. For optimum three-dimensional displays the computer requires the values to be plotted along each axis to be scaled to equal orders of magnitude. In order to obtain suitable scaled values the particle diameter corresponding to each channel number was multiplied by 10 and the logarithm of particle count was multiplied by 100 prior to plotting. The view is shown at an angle of 45° between the x- and y-axes from an angle of 15° above the horizontal. A computerized hidden line suppression algorithm was used to eliminate lines which could not be seen from the viewer's position. Each completed graph illustrates the particle distribution by size and count in the water column to depths as great as 1000 m.

5. Type 4 Graphs

A second type of three-dimensional perspective graph (Type 4) displays particle information for one depth in a given section (i.e. along a line of stations). The only

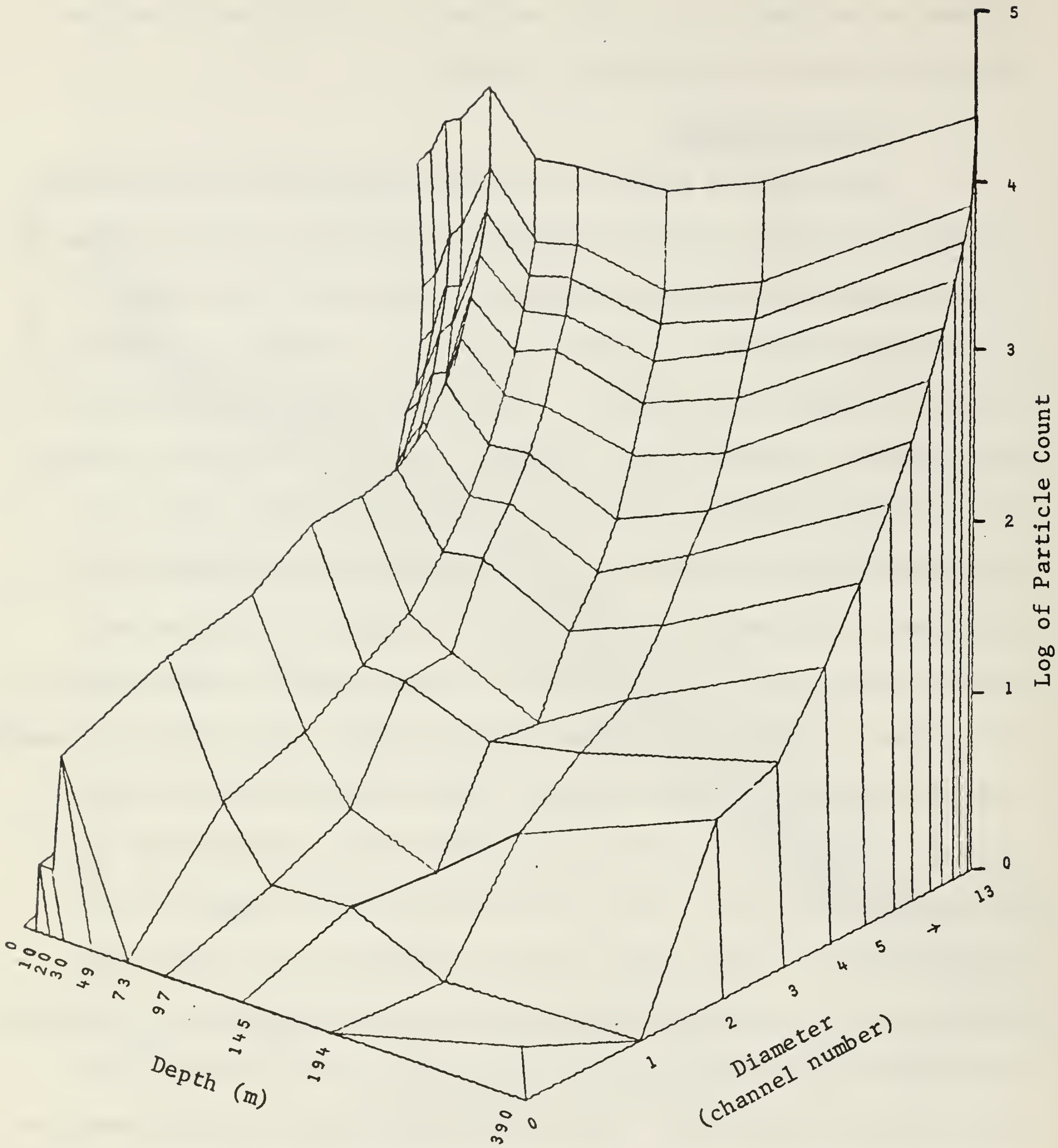

Figure 8. Type 3, Station B-6, Cruise 27 to 31 October 1973

change in the graphical presentation is that depth which had previously been plotted along the y-axis has been replaced by a station number. The station plotted to the left is closest to shore; all other stations are plotted as a distance in miles seaward of this base station. Each graph represents data for only one depth; plots at depths of 0 and 10 m for the E section are shown in Figures 9 and 10. All areas represented are plotted from nearshore stations toward the deeper offshore stations, except the A and B sections of the two northern cruises which extend across Monterey Bay from stations A-1 and B-13 in the south to A-12 and B-1 in the north. The vertical axis (log of particle count) of both Type 3 and Type 4 graphs illustrates relative values of counts for each individual graph only; comparison of counts between different stations or sections may only be made by referring back to the station data tables for actual count values.

These graphs represent a comparative view of the changes in number and size of particles as water depth and distance from shore increases. This type of display is useful in displaying changes in particle concentration as distance offshore from coastal particle sources (beaches, cliffs, rivers) is increased. For scaling purposes the distance in n mi seaward from the base station was multiplied by 100 prior to plotting.

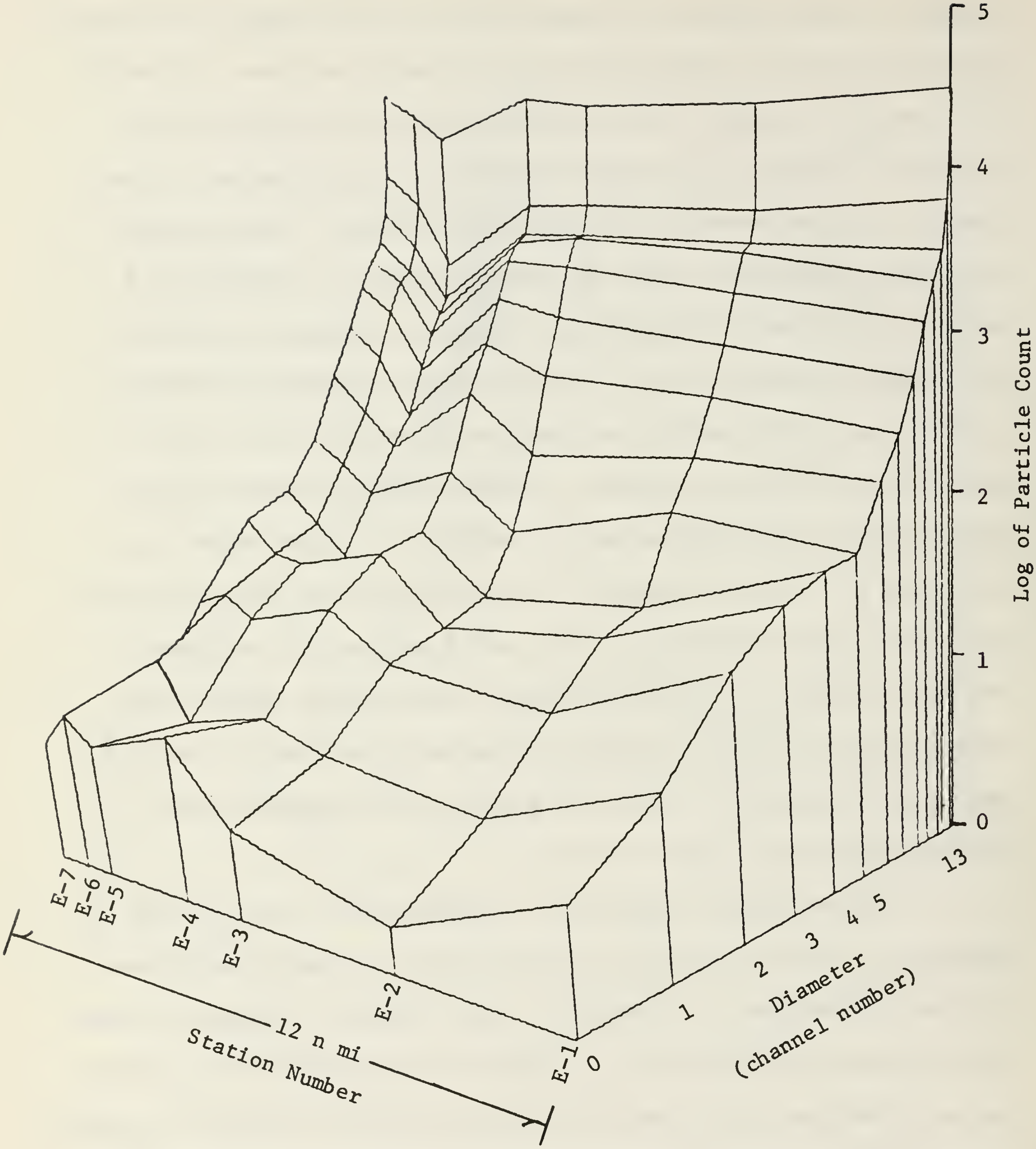

Figure 9. Type 4, Line E, 0 m, Cruise 27 to 31 October 1973

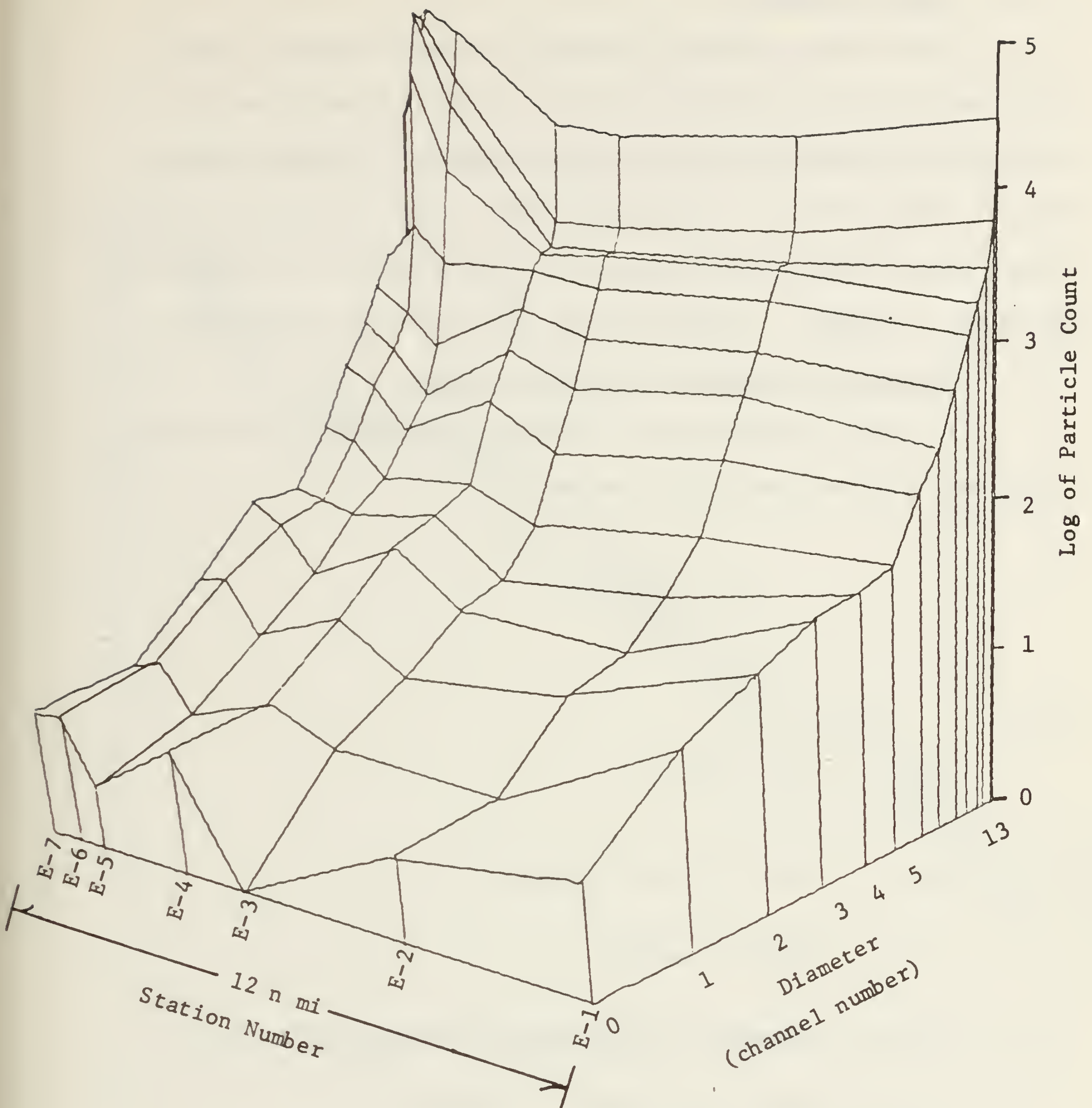

Figure 10. Type 4, Line E, 10 m, Cruise 27 to 31 October 1973

6. <u>Type 5 Graphs</u>

The final graphical display (Type 5 graph) plots the logarithm of particle diameter against the logarithm of the particle count per channel per depth. Plotted along a line of stations for a discrete depth this figure is basically an end view along the y-axis of the data that is plotted on the Type 4 graphs. A sample plot is shown as Figure 11.

7. <u>Tables of Observed C and K Values</u>

A Junge distribution for data gathered with a Model T Coulter counter may be given as:

$$M_i = K'D_i^{-C}$$

where:

$K' = K(1-2^{-C/3})$

M_i = count in any channel i

i = channel number

D_i = diameter in microns of channel i

K and C are constants.

If the logarithm (base 10) of the count in channel i is plotted as a function of the logarithm (base 10) of the diameter (in microns) of that channel (as are the Type 2 graphs) the slope of the graph is the constant C. Slopes

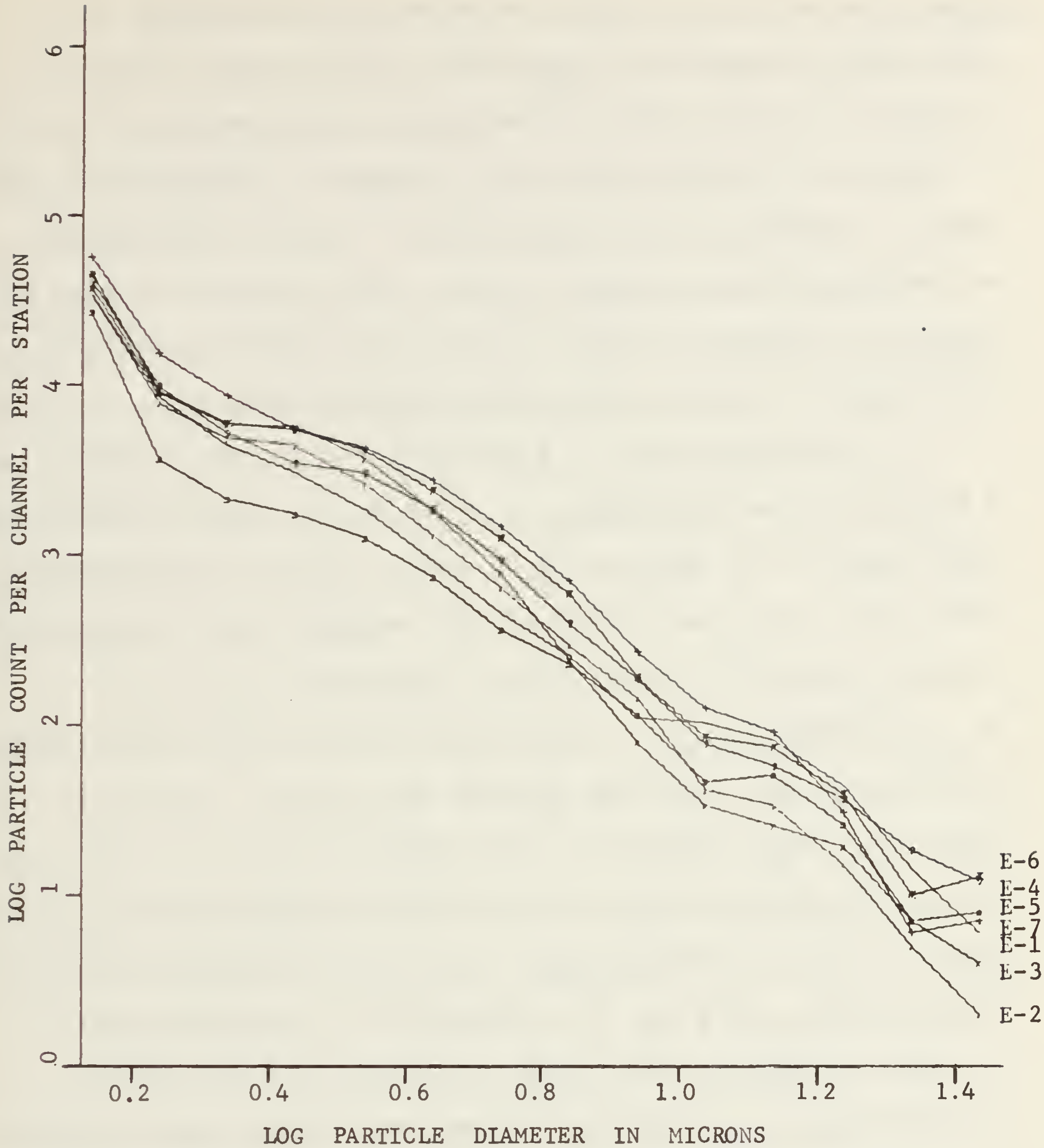

Figure 11. Type 5, Line E, 0 m, Cruise 27 to 31 October 1973

were calculated along the line segment corresponding to a given depth between the logarithm of the diameter scale values of 3.75 and 8.75 (corresponding to diameters of 2.37 to 7.50 μ). With the value for C known, K' can be found and used to compute K. All calculations of K were made using values from channel number 8 with a mean diameter of 4.36 μ. Tables of observed values of C and K for selected stations are located in each cruise data discussion section.

Observed values of K were divided by two to obtain a K value for a 1 ml sample in order that a direct comparison with Gordon's [7] data could be made. Gordon's measurements taken from the clear waters of the Sargasso Sea area indicated typical values for C of 2.4 to 3.1 and for K of 8×10^3 to 20×10^3 particles/ml. Approximately 75% of the total number of C values from the four cruises fell in the 2.4 to 3.1 range, but less than 50% of the values for the 15 to 18 April 1974 cruise (during the Upwelling Period) were in this range. This deviation is seen to be quite pronounced on the Type 2 graphs. Most of the "straight" lines, especially for shallow depths, show kinks or knees which are quite characteristic of plankton "blooms" in oceanic areas of high productivity. Values of C and K can be highly variable on the same graph for different size ranges because these plankton blooms can dominate the count in their own size range. To establish a basis for comparison all calculations were made over the same size range with a medium diameter of 4.36 μ.

Values of K which fell in the 8 to 20 x 10^3 particle/ml range were almost exclusively confined to depths greater than 100 m. Surface values generally occurred in a mean range from 50 to 200 x 10^3 particles/ml, but again significant deviations were noted. At two stations during both of the Davidson Current Period cruises values for K in excess of 1500 x 10^3 particles/ml were observed. During the Upwelling Period cruise average surface values of K were in the 20 to 50 x 10^3 particles/ml range. It was noted that K values usually decreased with depth to approximately 100 m, while below this depth a stable background count of 8 to 20 x 10^3 particles/ml was generally maintained.

The great difference between C and K values for California coastal waters and those of the Sargasso Sea is not surprising. Waters of the Sargasso Sea form part of the center of the North Atlantic Gyre. In this area there is a very small exchange of water, and no upwelling takes place to bring nutrients from below; consequently the area is almost a biological desert. The values of C and K found by Bader [1] are characteristic of this "clear" ocean water. Conversely, water which is rich in nutrients and capable of sustaining large biological populations will produce curves with many biologically induced peaks characteristic of particular species and will lead to large variations in values for C and K. In addition to a constant supply of new particles from the land, shallow coastal waters are constantly being mixed due to the combined action of wind, tides and currents interacting with the bottom and shore, thus inhibiting the natural process of size sorting by settling, and higher particle counts, especially for larger diameters, are a natural consequence.

C. CRUISE DATA DISCUSSION

Complete station data tables, graphs, and tables of C and K values for each cruise are presented in a separate technical report [6]. Some representative samples of the data are provided in support of the cruise data discussions presented below.

1. <u>27 to 31 October 1973</u>

As is normally characteristic of the Oceanic Period, surface temperatures for the stations occupied during this cruise averaged in excess of 13 °C. One notable exception was station G-2 which displayed a very localized area of cold surface water (11.4°C) probably indicative of a patch of upwelled water. A sharp thermocline varying from just below the surface to a depth of approximately 40 m over the canyon and at some offshore stations was observed throughout the area. This temperature profile produced a strong pycnocline causing large numbers of particles in a wide range of sizes to become trapped.

The Type 1 graphs for the stations along lines I and K are quite indicative of the pycnocline acting as a particle trap. In most cases a very definite break is evident (especially on the right side corresponding to larger size particles), as depths above the thermocline have generally increasing cumulative volumes and those below the thermocline remain approximately horizontal (constant volume) or tend to fall off. Invariably the depth at which curves break in opposite directions coincides with the thermocline depth. The Type 1 graph for station I-6 (Figure 12) provides a good example. Cumulative volume lines for depths 0, 5, 10, 20 and 30 m show a dramatic increase for large diameter particles. At 50 m the cumulative volume for all sizes is much lower, and 75 m indicates a drop off. The XBT data indicate that the thermocline for this station is located at a depth of 33 m.

The two Type 3 graphs (Stations C-3, and I-1) included in Figures 13 and 14 display large particle counts across the full range of particle diameters at depths which correspond very closely with the thermocline (and hence, pycnocline) depth at each station. These graphs also indicate a general decline in the number of larger particles with depth. Smaller diameter particles normally show maxima near the thermocline, but counts remain relatively constant at greater depths.

Type 4 graphs (for 0 and 10 m) were made for sections covered by the A, B, E, G, I and K station lines. Stations A-5, A-6, A-7, A-8 and B-6, B-7, B-8, and B-9 lie over the Monterey Submarine Canyon. Graphs for the A and B sections clearly show a "reflection" of the bottom topography, as the

Figure 12. Type 1, Station I-6, Cruise 27 to 31 October 1973

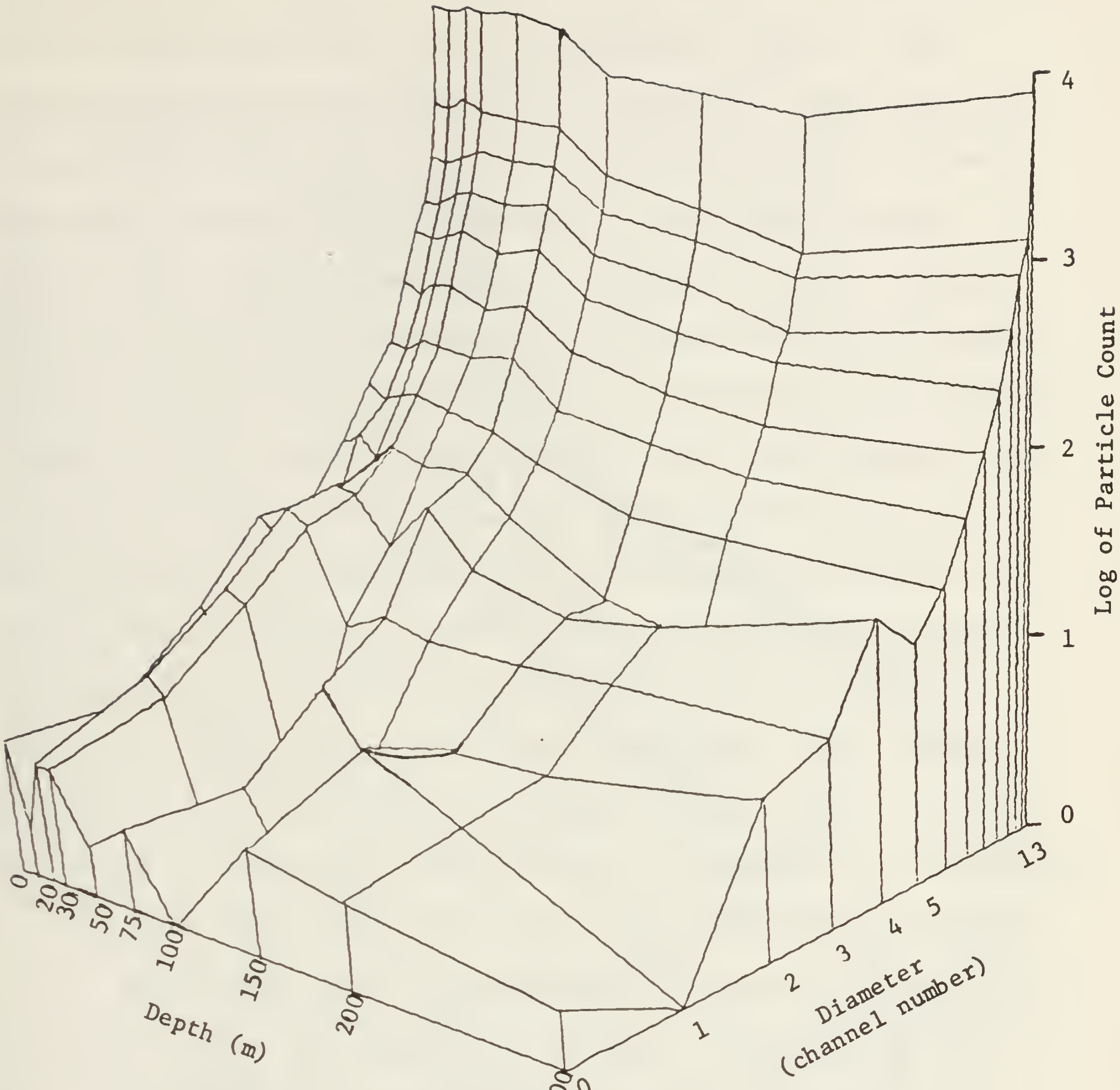

Figure 13. Type 3, Station C-3, Cruise 27 to 31 October 1973

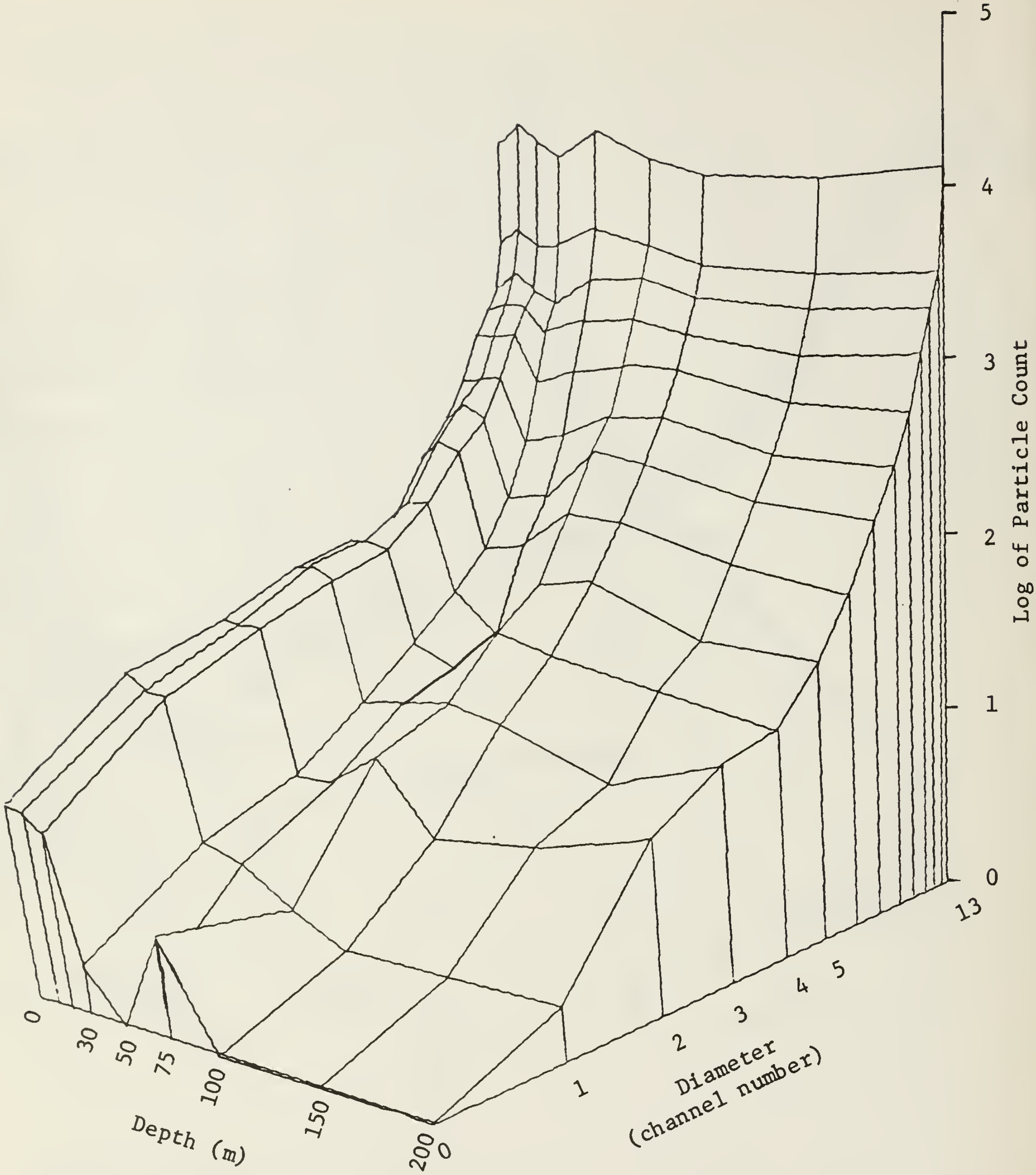

Figure 14. Type 3, Station I-1, Cruise 27 to 31 October 1973

counts for the "canyon stations" mentioned show a definite decline along the entire range of particle sizes. (Some sample plots are shown in Figures 15 and 16.) This drop-off in counts is particularly noticeable for the larger diameter particles. Shallow water stations at both ends of each section line show increased counts compared to the "canyon stations" for all size ranges. This agrees with the findings of Sheldon, Evelyn, and Parsons [16] in Departure Bay, British Columbia which lead to the suggestion that areas where larger size particles are confined mainly to the surface may be characteristic of rocky coasts or relatively deep water. In shallow water, counts of larger size particles may increase with depth due to settling. Carder, Beardsley and Pak [4] also found concentrations of particles to be higher close to shore where wave action, biological action, and run-off all worked to maintain a large amount of material in suspension.

Individual data tables for stations in line sections E, G, I and K indicate very high relative particle counts for channels 0 and 1 for almost all depths. However some drop-off at these sizes is noted for stations at the seaward end of the station lines where water depths exceed 100 m. Examples include stations I-1, I-2, K-9, K-10, K-11, E-1, E-2, E-3, G-4, G-5, G-6, and G-7. It is to be noted that the maximum counts for large diameter particles for all four of these section lines occur for stations in the middle of the lines and drop off at both the shoreward station and all

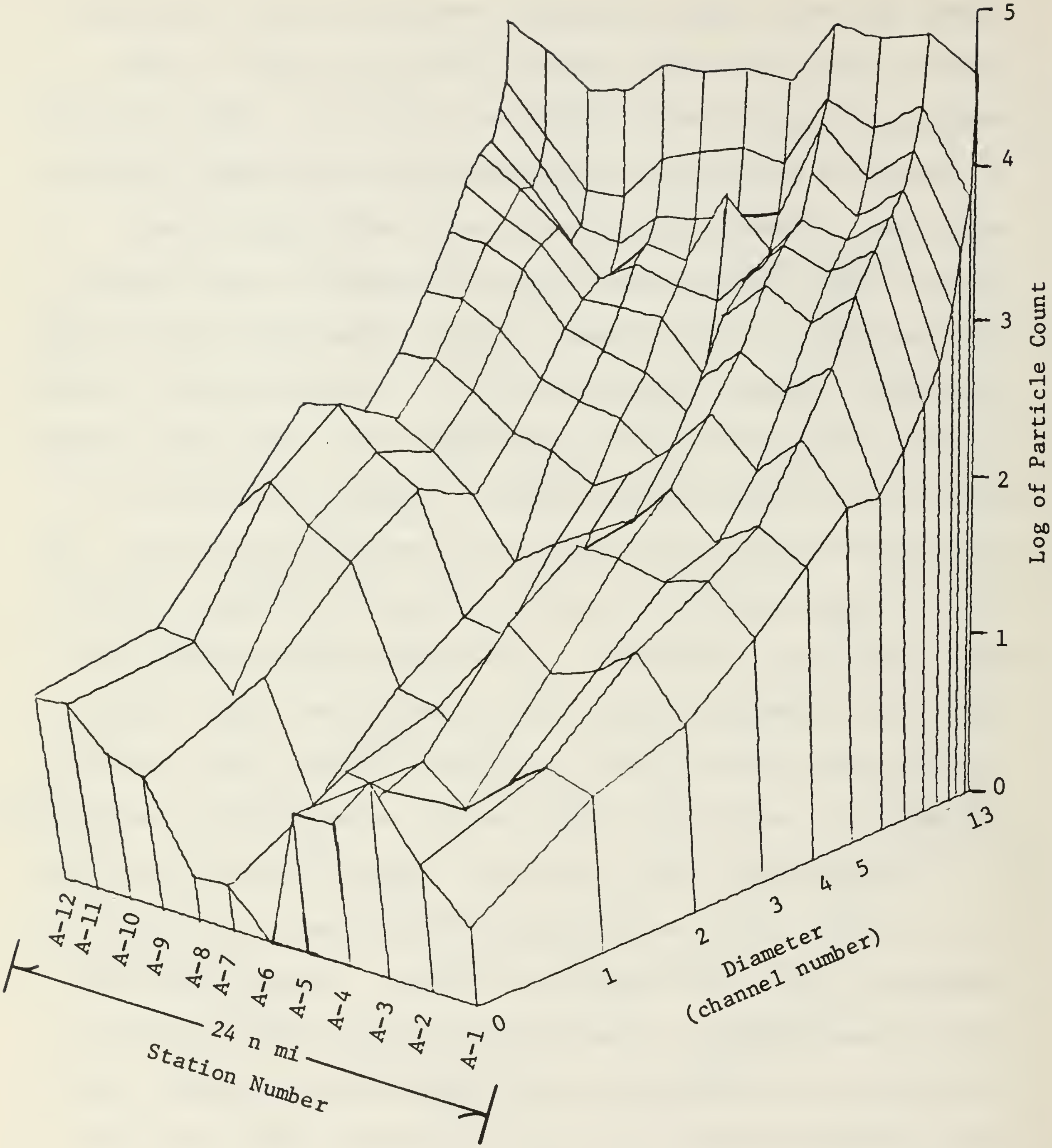

Figure 15. Type 4, Line A, 0 m, Cruise 27 to 31 October 1973

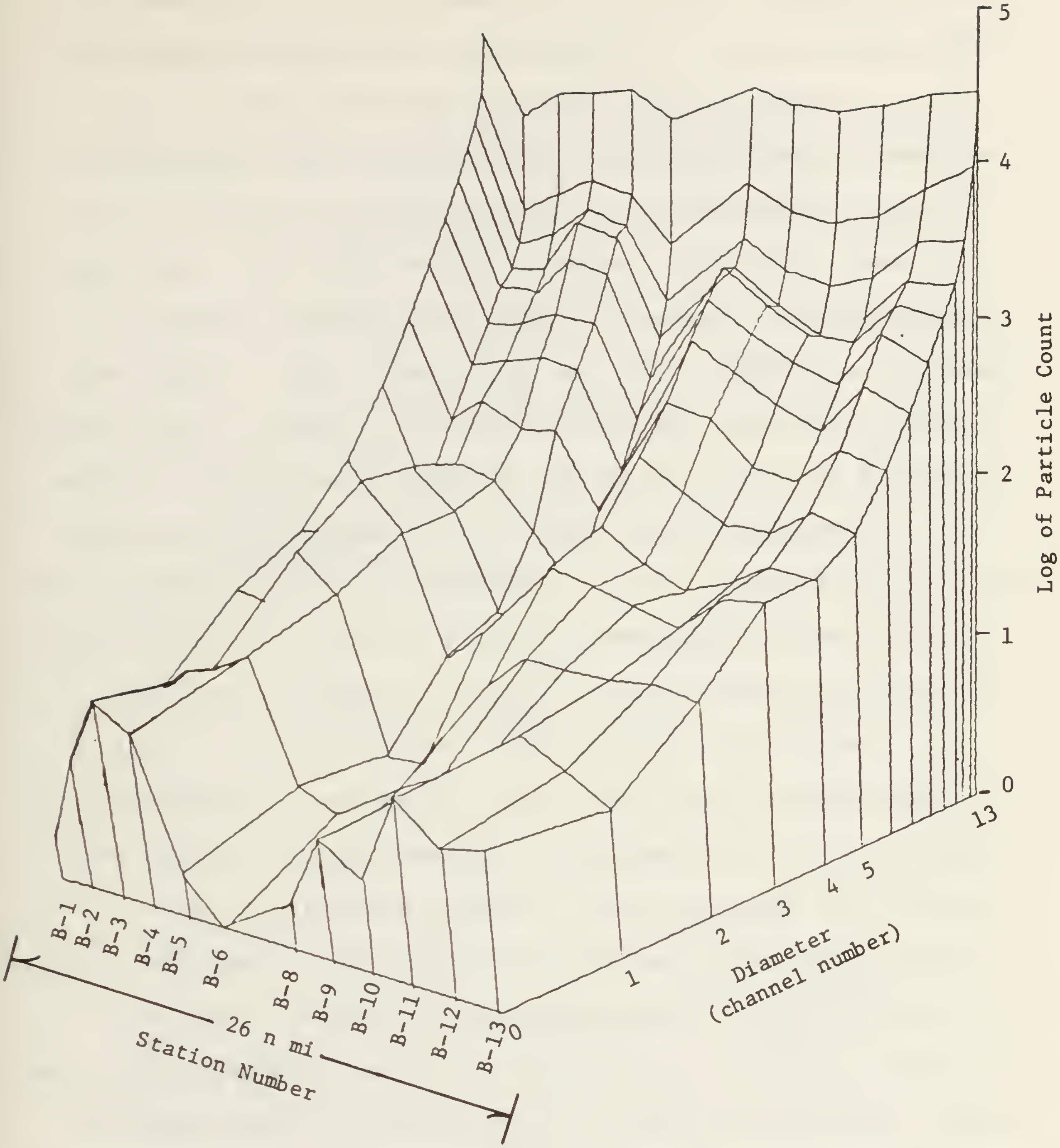

Figure 16. Type 4, Line B, 10 m, Cruise 27 to 31 October 1973

seaward stations with depths exceeding 100 m. An example is shown in Figure 17. This distribution may be connected with the coastal current normally characteristic of the Davidson Current Period, but insufficient data were gathered to allow a determination of the existence or extent of such a current. Sutcliff, Sheldon, Prakash and Gordon [21] have demonstrated an increase in particulate matter beneath a Langmuir circulation induced convergence area. Since convergence areas are characteristic of the Oceanic Period these increased particle counts may be indicators of such regions.

Temperature data show a small region of relatively cold surface water (11.5 °C) centered around stations G-2 and G-3, but greatly increased particle counts do not seem to correspond closely with this area of possible upwelling.

Tables of C and K values observed for this cruise are included as Figure 18. Over 85% of the C values fall in the 2.4 to 3.1 range, which compares quite favorably with Gordon's [7] observations. Average values for K fall in the 30 to 300 x 10^3 particles/ml region, but values did range as high as 600 x 10^3 particles/ml. Localized areas of extremely high K are associated with shallow highly protected areas (stations A-12 and B-1) and areas of colder possibly upwelled water (G-1, G-4 & G-5). Values for K were generally found to decrease with depth.

2. <u>14 to 17 January 1975</u>

Temperature profiles plotted from XBT and STD data gathered during this cruise were typical of the Davidson

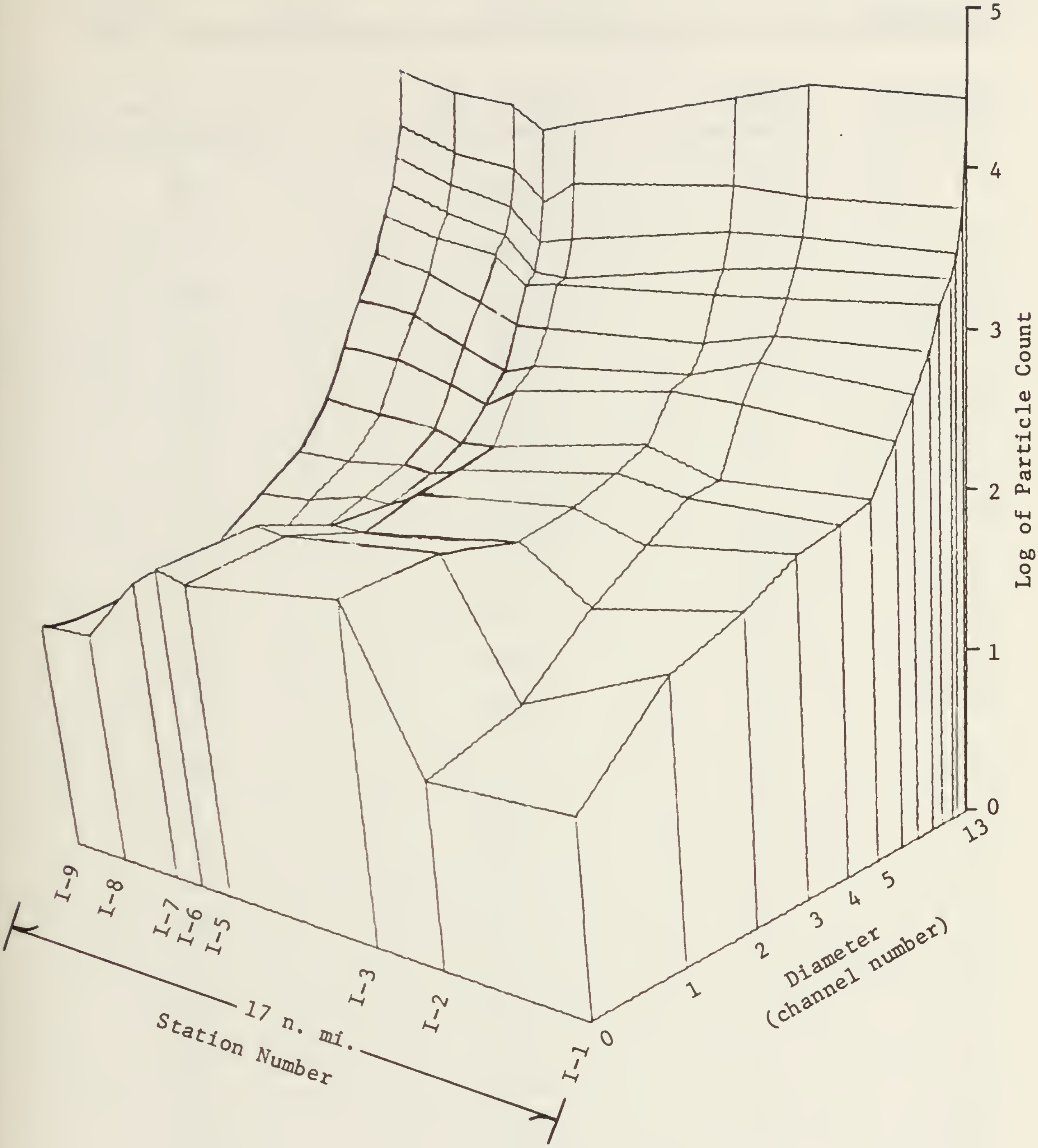

Figure 17. Type 4, Line I, 0 m, Cruise 27 to 31 October 1973

Observed C and K Values for Cruise 27 to 31 October 1973

Station Number	Depth (meters)	Slope (C) (count/micron)	K Value ($x10^3$) (particles/ml)
A-1	0	2.66	27
	28	3.10	78
A-2	0	2.60	21
A-7	0	3.00	130
A-10	0	2.96	366
	20	2.96	211
A-12	0	2.48	546
B-1	0	2.64	607
B-4	0	3.00	166
B-7	0	2.72	59
	200	2.72	10
B-8	29	2.56	35
B-9	50	3.30	30
B-10	50	2.98	23
B-12	0	2.16	40
	75	2.78	30
C-3	0	2.76	50
C-4	0	3.10	85
E-1	0	2.92	68
E-2	0	2.80	83
E-4	0	2.64	125
E-7	0	2.44	112
F-1	0	2.52	104
G-1	0	2.68	221
G-4	0	2.64	173
G-5	0	2.78	141
G-7	0	2.66	66
H-2	0	2.66	90

Figure 18

Station Number	Depth (meters)	Slope (C) (count/micron)	K Value ($x10^3$) (particles/ml)
I-1	0	2.10	34
	200	2.94	30
I-3	0	2.48	27
	75	2.36	56
I-5	0	2.16	41
I-9	5	2.52	171
J-2	0	2.04	89
J-4	0	2.60	230
K-2	0	2.54	92
K-8	0	1.96	51
	50	2.84	33
K-10	0	2.86	91
K-11	0	2.64	75

Figure 18 (cont'd)

Current Period. All stations exhibited isothermal conditions (≈ 11.5 °C) to a depth of at least 40 m and often to as deep as 100 m. Shallow water stations (less than 50 m) were usually isothermal to the bottom.

Two station data tables and Type 1 and 2 graphs (for station E-1) are presented as Figures 19, 20 and 21; they represent typical data from this cruise. In general the Type 1 graphs follow the horizontal straight line-constant volume hypothesis much more closely than those of the previous cruise. In addition the thermocline breaks in the cumulative volume curves observed in the previous cruise data are not seen here, probably due to the relatively weaker thermocline and a deeper mixed layer. Four Type 3 graphs were also plotted to allow a direct comparison of particle distribution with depth between similar stations during different oceanic periods. Section graphs were plotted for station lines A, B, E and E.

Generally station data tables for this cruise indicate a continued high level of particles in the water column; however due to the lack of strong thermocline exceptionally high counts do not correspond with any set depth but may appear at any depth in the mixed layer down to 100 m. Type 3 graphs for stations A-6, B-6, C-3 and G-7 (Figures 22 to 25) illustrate some typical distributions. Note that the station A-6 plot (Figure 22) shows that the maximum count for larger size particles occurs at 20 m, but maxima for the

COULTER COUNTER DATA   SHIP R/V ACANIA

STATION D-3 , 1305 HRS PST, 36 DEG 43.0 MIN N, 122 DEG 18.8 MIN W. 15 JAN 75

PARTICLE DIAMETERS IN MICRONS. VOLUMES IN CUBIC MICRONS PER 2ML SEAWATER SAMPLE

PARTICLE COUNT / VOLUME PER COUNT

DIA	CH#	0	10	20	30	50	75	100	200	300	500	700	800	1000
SAMPLE DEPTH IN METERS														
27.66	0	10 / 110872	8 / 88697	8 / 88697	6 / 66523	4 / 44348	0 / 0	1 / 11087	1 / 11087	2 / 22174	1 / 11087	3 / 33261	1 / 11087	0 / 0
21.96	1	28 / 155223	11 / 63979	11 / 63979	18 / 99784	11 / 60979	0 / 0	2 / 22174	0 / 0	5 / 27718	7 / 38805	3 / 16630	0 / 0	1 / 5543
17.43	2	56 / 155220	24 / 66523	17 / 47123	51 / 141361	29 / 80382	11 / 30489	8 / 22174	5 / 13859	15 / 41577	17 / 47123	4 / 11087	6 / 16630	5 / 13859
13.83	3	96 / 133046	73 / 101170	47 / 65137	104 / 144133	63 / 87311	21 / 29103	14 / 19402	11 / 15244	18 / 24946	26 / 36033	16 / 22174	16 / 22174	16 / 22174
10.98	4	183 / 124731	121 / 83847	98 / 67909	165 / 114336	110 / 76224	26 / 18016	19 / 13166	27 / 18709	46 / 31875	28 / 19402	19 / 13166	19 / 13166	16 / 11087
8.71	5	431 / 149338	401 / 138936	263 / 91123	364 / 126117	261 / 90435	67 / 23213	45 / 15591	30 / 10394	73 / 25292	60 / 20788	35 / 12126	31 / 10740	39 / 13512
6.92	6	745 / 129362	707 / 122479	608 / 105328	889 / 154038	641 / 111045	137 / 23733	111 / 19229	87 / 15071	136 / 23563	144 / 24948	81 / 14032	43 / 7449	63 / 10913
5.49	7	1227 / 106281	1281 / 110958	1196 / 103598	1687 / 146125	1512 / 130967	266 / 23040	175 / 15158	180 / 15591	248 / 21481	193 / 16457	188 / 16284	102 / 8835	139 / 12043
4.36	8	2138 / 92595	2287 / 99048	1935 / 83803	2815 / 121916	2637 / 114206	558 / 24380	342 / 14811	268 / 11606	448 / 19402	347 / 15028	345 / 14941	186 / 8055	215 / 9311
3.46	9	3461 / 74966	3524 / 76289	3514 / 76094	4718 / 102166	4925 / 106649	981 / 21243	653 / 14140	520 / 11263	763 / 16522	811 / 17561	621 / 13447	365 / 7903	413 / 8943
2.74	10	4392 / 71332	4291 / 46460	3341 / 53261	7213 / 78162	8137 / 87777	1682 / 18211	1233 / 13025	884 / 9571	1334 / 14423	75470 / 817140	1145 / 12337	667 / 7221	791 / 8564
2.18	11	16706 / 101268	7113 / 38507	10316 / 55847	11623 / 63057	14055 / 76089	2529 / 13691	2033 / 11036	1448 / 7839	2163 / 11709	81537 / 437334	1916 / 10372	1053 / 5700	1304 / 7061
1.73	12	45593 / 123412	17977 / 48660	21719 / 58789	19293 / 52223	25726 / 69581	4015 / 10867	3180 / 8637	2166 / 5863	3992 / 10805	327725 / 887085	3252 / 8832	1792 / 4850	2171 / 5876
1.37	13	138376 / 138327	64885 / 67316	82659 / 114836	70156 / 93909	76188 / 103114	16619 / 22519	14224 / 19251	11444 / 15582	18137 / 24621	604607 / 821264	15680 / 21232	9858 / 13438	11533 / 15683
TOTAL VOL (CH 0-13) IN 2ML SW		1715394	1170369	1077519	1502520	1239102	258205	218821	161176	316125	3239664	219951	137246	144601
UNCERT(±)		128940	102657	95740	114846	93268	28111	45797	32150	58244	62325	49973	32082	26458

COULTER COUNTER DATA   SHIP R/V ACANIA

STATION E-1 , 1515 HRS PST, 36 DEG 47.0 MIN N, 122 DEG 14.7 MIN W. 16 JAN 75

PARTICLE DIAMETERS IN MICRONS. VOLUMES IN CUBIC MICRONS PER 2ML SEAWATER SAMPLE

PARTICLE COUNT / VOLUME PER COUNT

DIA	CH#	0	10	20	30	50	75	100	200	300	400	500
SAMPLE DEPTH IN METERS												
27.66	0	25 / 277180	16 / 177395	5 / 55436	6 / 66523	2 / 22174	1 / 11087	0 / 0	1 / 11087	3 / 33261	3 / 33261	3 / 33261
21.96	1	32 / 177395	24 / 133046	8 / 44348	4 / 22174	1 / 5543	0 / 0	2 / 11087	8 / 44348	1 / 5543	1 / 5543	2 / 11087
17.43	2	57 / 157992	30 / 83154	12 / 33261	10 / 27718	6 / 16630	6 / 16630	6 / 16630	10 / 27718	5 / 13859	3 / 8315	5 / 13859
13.83	3	93 / 128888	80 / 110872	48 / 66523	22 / 30489	23 / 31875	7 / 9701	11 / 15244	20 / 27718	12 / 16630	16 / 22174	11 / 15244
10.98	4	165 / 114336	129 / 89390	84 / 58207	73 / 50585	27 / 18709	12 / 8315	23 / 15937	33 / 22867	12 / 8315	18 / 12473	24 / 16630
8.71	5	373 / 129235	255 / 88351	202 / 69988	213 / 73799	62 / 21481	38 / 13166	34 / 11780	76 / 26332	46 / 15937	47 / 16284	41 / 14205
6.92	6	954 / 165268	728 / 126117	612 / 106021	612 / 105436	140 / 24253	62 / 10740	70 / 12126	146 / 25292	74 / 12819	75 / 12992	88 / 15244
5.49	7	1539 / 133307	1501 / 130014	1433 / 123824	1416 / 122652	330 / 28584	156 / 13512	120 / 10394	256 / 22174	164 / 14205	172 / 14898	197 / 17063
4.36	8	2831 / 121339	2815 / 121916	2867 / 124168	2956 / 127936	761 / 32958	465 / 20138	213 / 9224	391 / 16933	406 / 17583	338 / 14638	321 / 13902
3.46	9	4515 / 97771	4349 / 94176	5255 / 113795	6158 / 133349	1770 / 38328	1773 / 38328	418 / 9051	662 / 14292	753 / 16305	637 / 13794	719 / 15569
2.74	10	7313 / 84594	5597 / 65000	4893 / 55778	11444 / 123938	3133 / 34571	3193 / 34571	759 / 8651	1247 / 13521	1658 / 17951	1153 / 12451	1451 / 15710
2.18	11	22559 / 111299	8570 / 46395	13921 / 75141	22893 / 113137	6677 / 36147	6677 / 36147	1413 / 7653	1959 / 10605	3219 / 17426	1987 / 10767	2658 / 14389
1.73	12	50060 / 135504	18976 / 51369	23333 / 63150	50478 / 139367	24195 / 65491	24195 / 65491	2272 / 6149	3467 / 9384	6842 / 18493	3451 / 9341	5012 / 13620
1.37	13	161765 / 191843	62857 / 85071	72274 / 99113	105405 / 142738	54222 / 73385	54222 / 73385	14957 / 19566	18163 / 24355	23765 / 32162	14145 / 19133	22361 / 30263
TOTAL VOL (CH 0-13) IN 2ML SW		2023318	1397861	1124790	1254031	450129	351211	153472	296806	240469	206034	240046
UNCERT(±)		151986	126259	64819	79075	48501	32155	28838	54580	45735	45507	48727

Figure 19. Station Data Tables (from Reference 6)

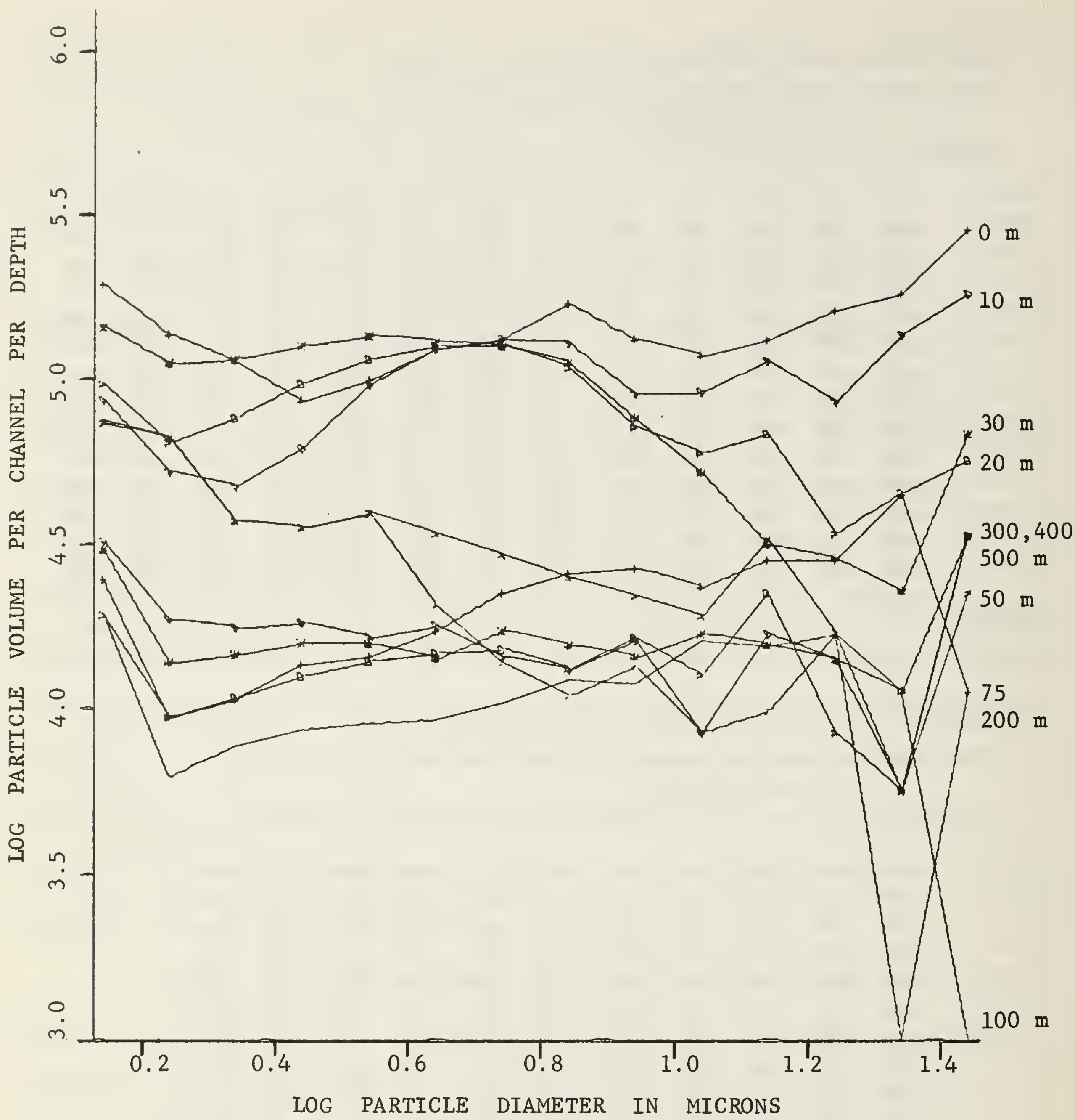

Figure 20. Type 1, Station E-1, Cruise 14 to 17 January 1975

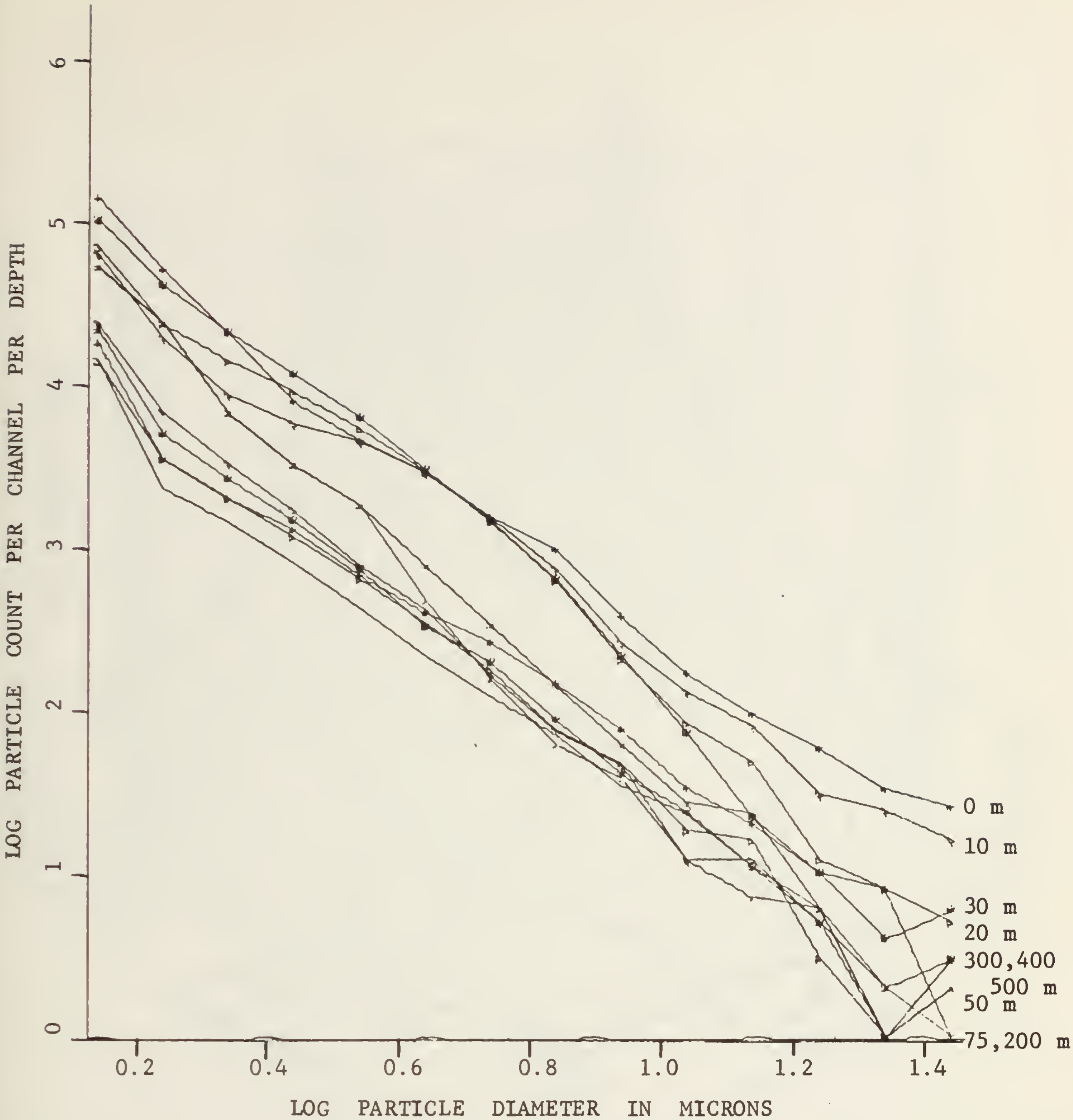

Figure 21. Type 2, Station E-1, Cruise 14 to 17 January 1975

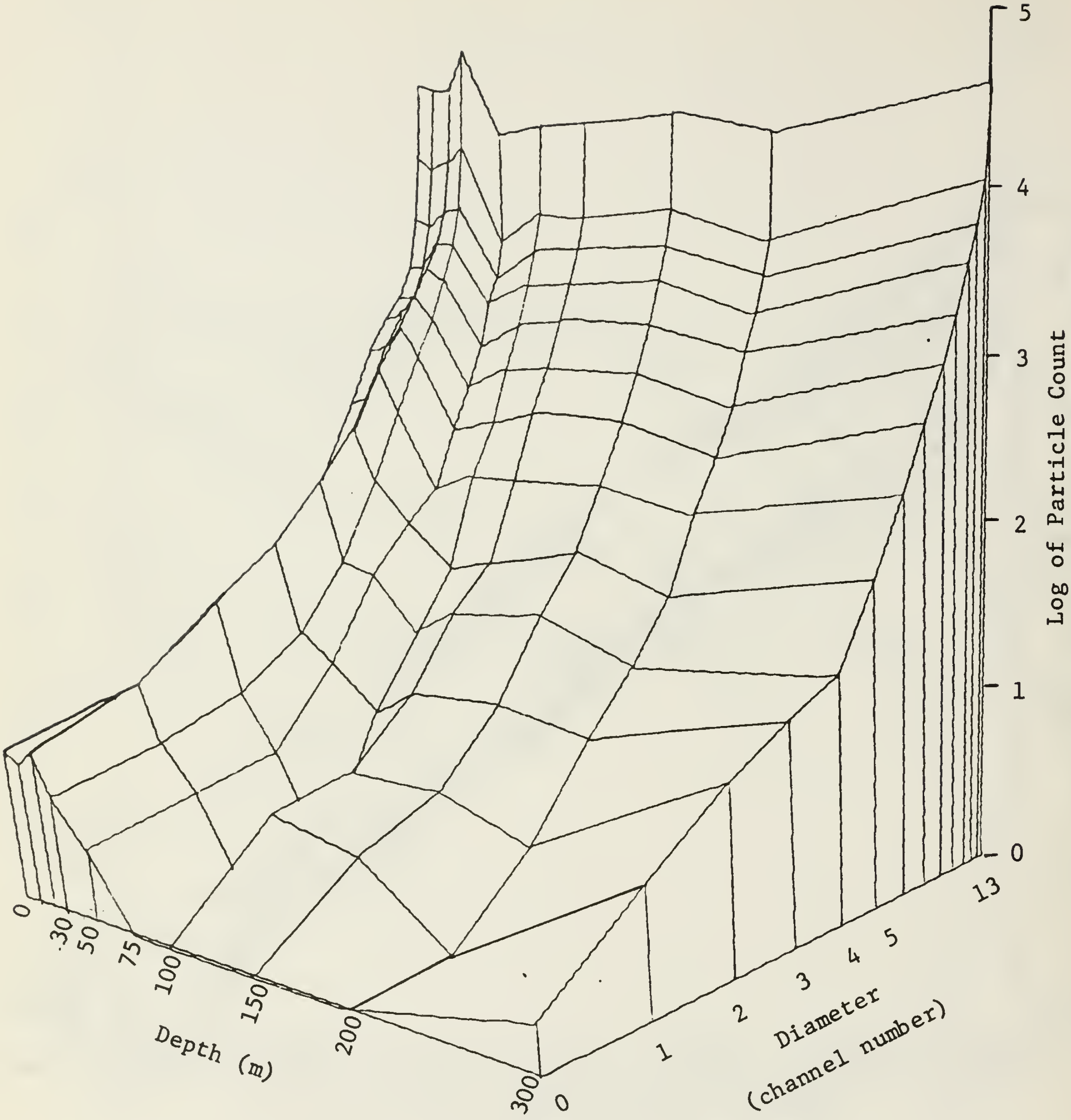

Figure 22. Type 3, Station A-6, Cruise 14 to 17 January 1975

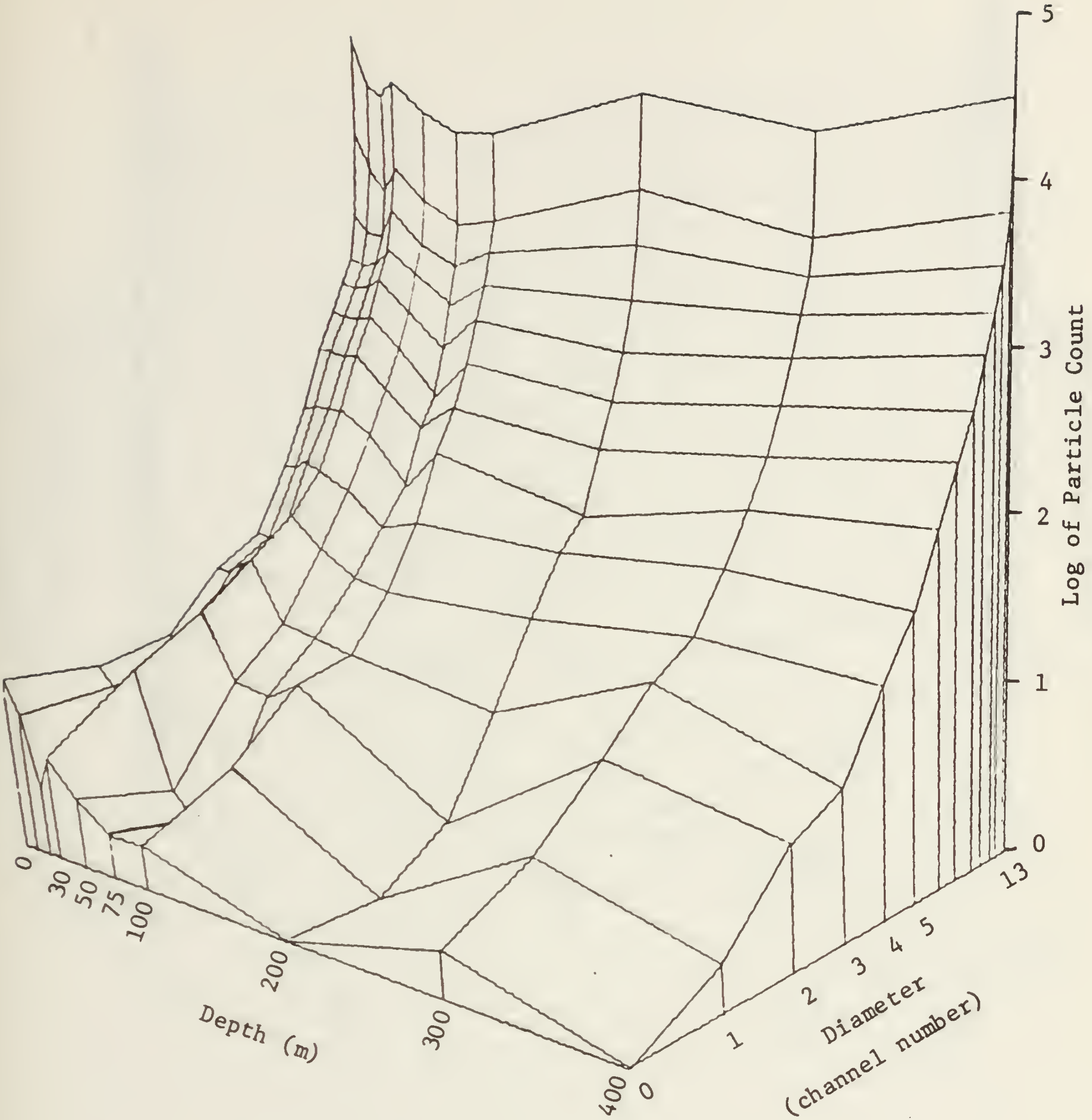

Figure 23. Type 3, Station B-6, Cruise 14 to 17 January 1975

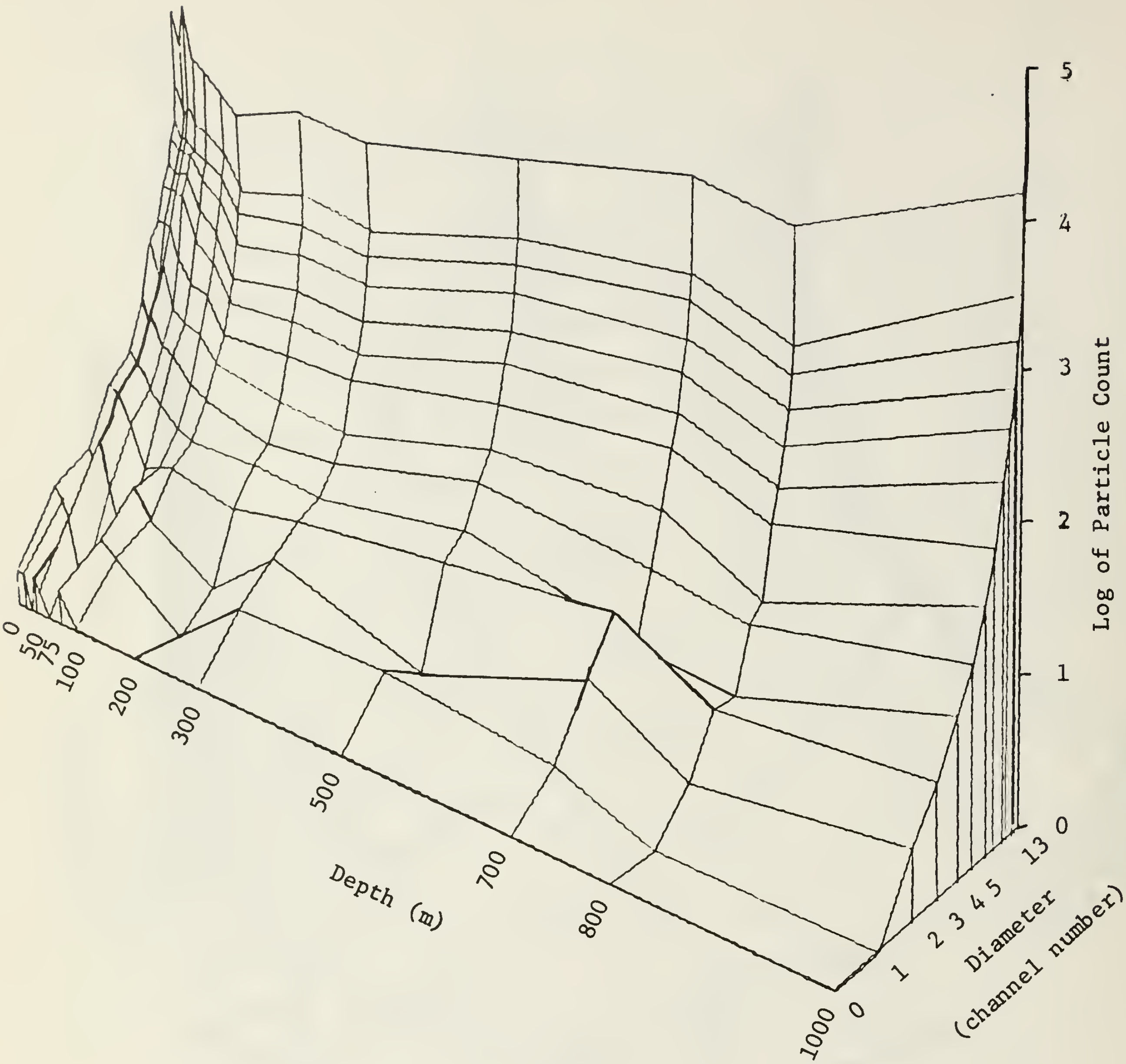

Figure 24. Type 3, Station C-3, Cruise 14 to 17 January 1975

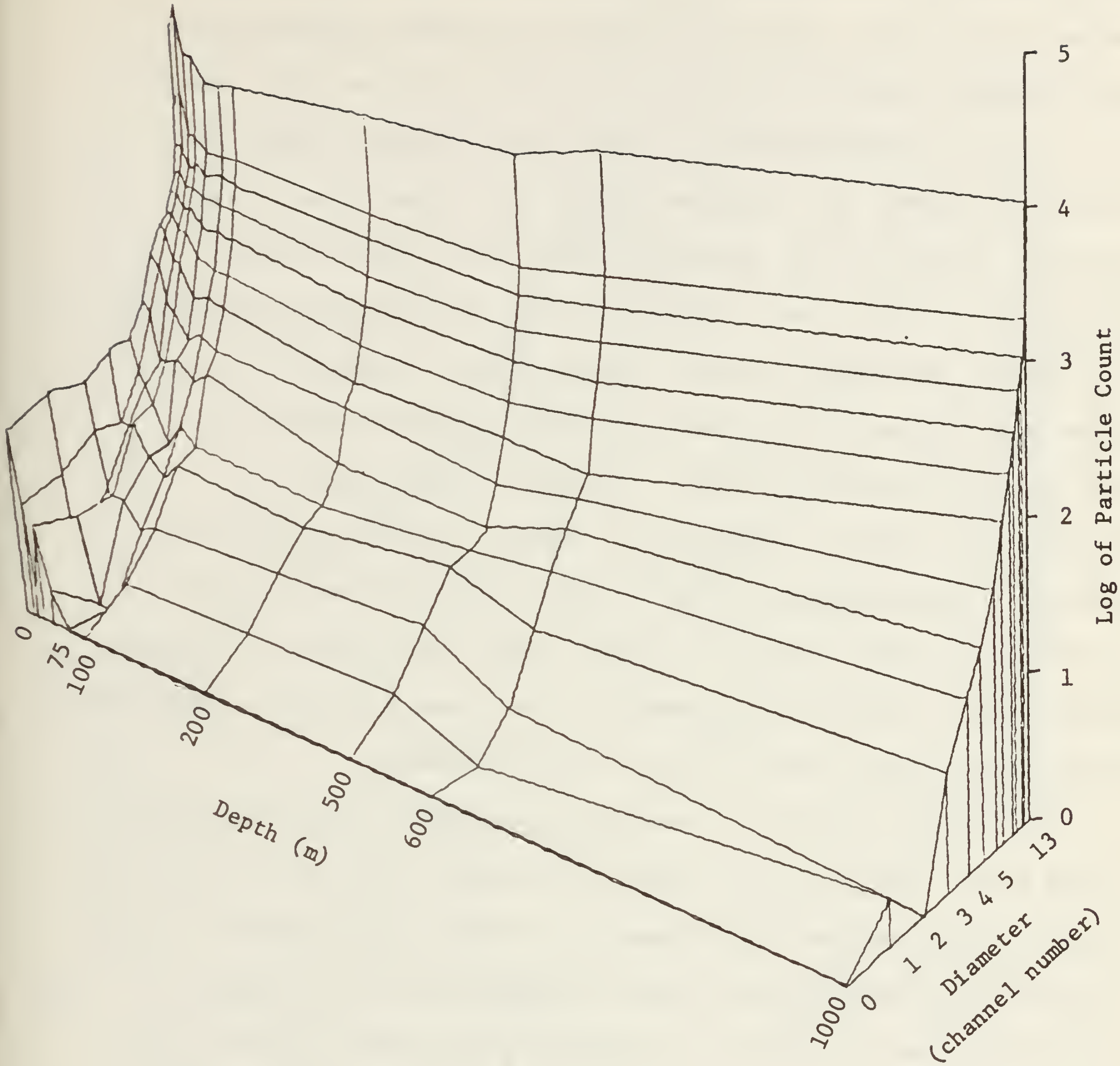

Figure 25. Type 3, Station G-7, Cruise 14 to 17 January 1975

size ranges corresponding to channels 11, 12 and 13 do not occur until 30 m. Very high particle counts indicated for the surface layer of station G-7 (Figure 25) are the result of a density trap caused by a very low relative value for salinity between the surface and 10 m. This anomaly was noted to exist at all stations along the G line and at stations C-2, C-3, D-3, and E-1. The cause of this phenomena is unknown but may be linked to the Ekman transport of less dense surface water shoreward which is characteristic of the Davidson Current Period. Graphs for stations C-3 (Figure 24) and G-7 (Figure 25) appear slightly different because a new scaling factor had to be introduced to allow plotting of depths down to 1000 m. As was pointed out above, these Type 3 graphs also seem to tend toward stable background count levels as a depth of 100 m is exceeded.

Unlike the Type 4 section graphs for station lines A and B for the earlier cruise, the plots for the 14 to 17 January 1975 cruise do not seem to reflect the canyon topography or the shallow water at each end of the section lines (Figures 26 and 27). However it is seen that the line A plots (0 and 10 m) show much more variability from station to station and for different particle diameters than do the line B plots. Reasons for this are unclear but a closer proximity to the shoreline and the discharges from the Salinas River, Elkhorn Slough, and Pajaro River are probably contributing factors.

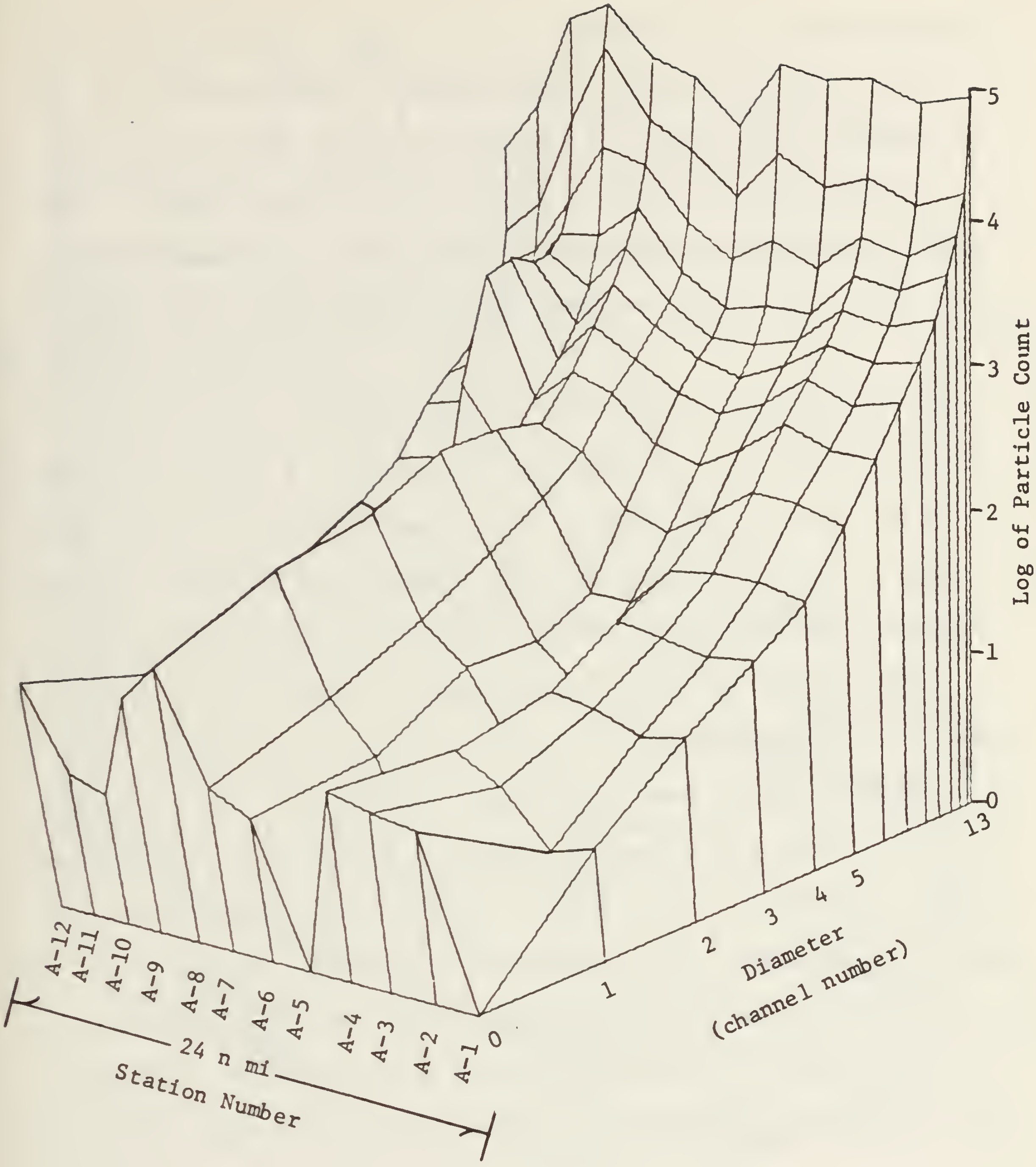

Figure 26. Type 4, Line A, 0 m, Cruise 14 to 17 January 1975

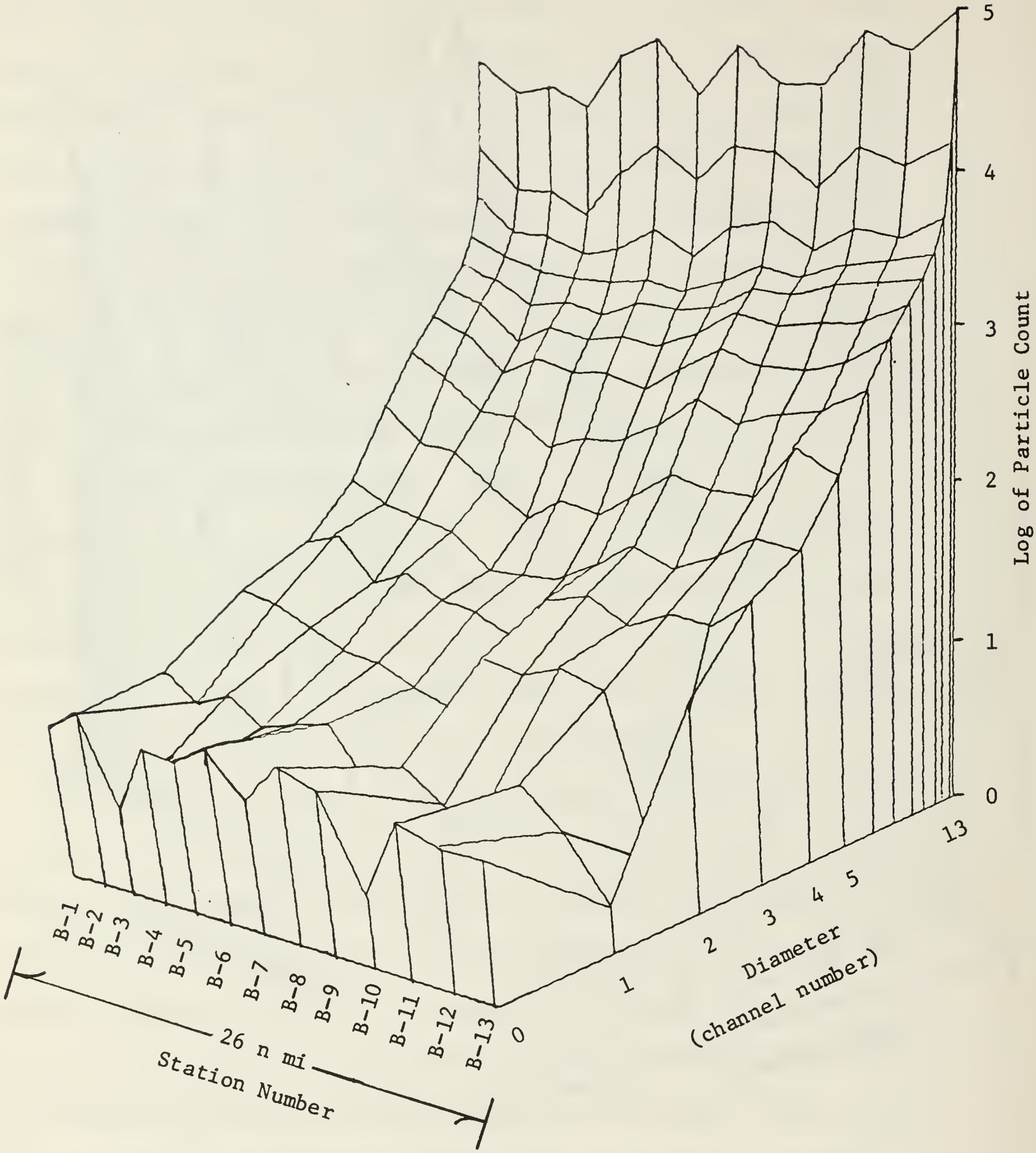

Figure 27. Type 4, Line B, 0 m, Cruise 14 to 17 January 1975

Sections E and G do not appear to be very different for the two northern cruises, but there does seem to be a tendency for the seaward stations of the January cruise to have higher counts in the channels which correspond to larger diameters. The density anomaly created by the low surface salinity already mentioned may possibly be the cause of this condition.

It is also interesting to note the large peak for channels 12 to 2 at station E-5; this is indicated by both the Type 4 and 5 surface curves for the E section. The Type 4 graph at 10 m completely lacks this feature and is a good illustration of how localized and variable particle distributions for this area can be (Figures 28 and 29).

Approximately 71% of the values observed for C fell in the 2.4 to 3.1 range, and all but two of the varient values were confined to an area extending parallel to the coast through stations E-7, F-1 and G-1 (Figure 30). Four of the varient values are associated with stations E-7 and F-1, which show very large concentrations of particles at a depth of 30 m. Values for C and K at 30 m for these two stations were among the highest encountered during the four cruises.

In general the average values for K observed for this cruise were similar to those observed for the same stations during the Oceanic Period but extreme values were significantly higher. Average values for K fell in the 50 to 300

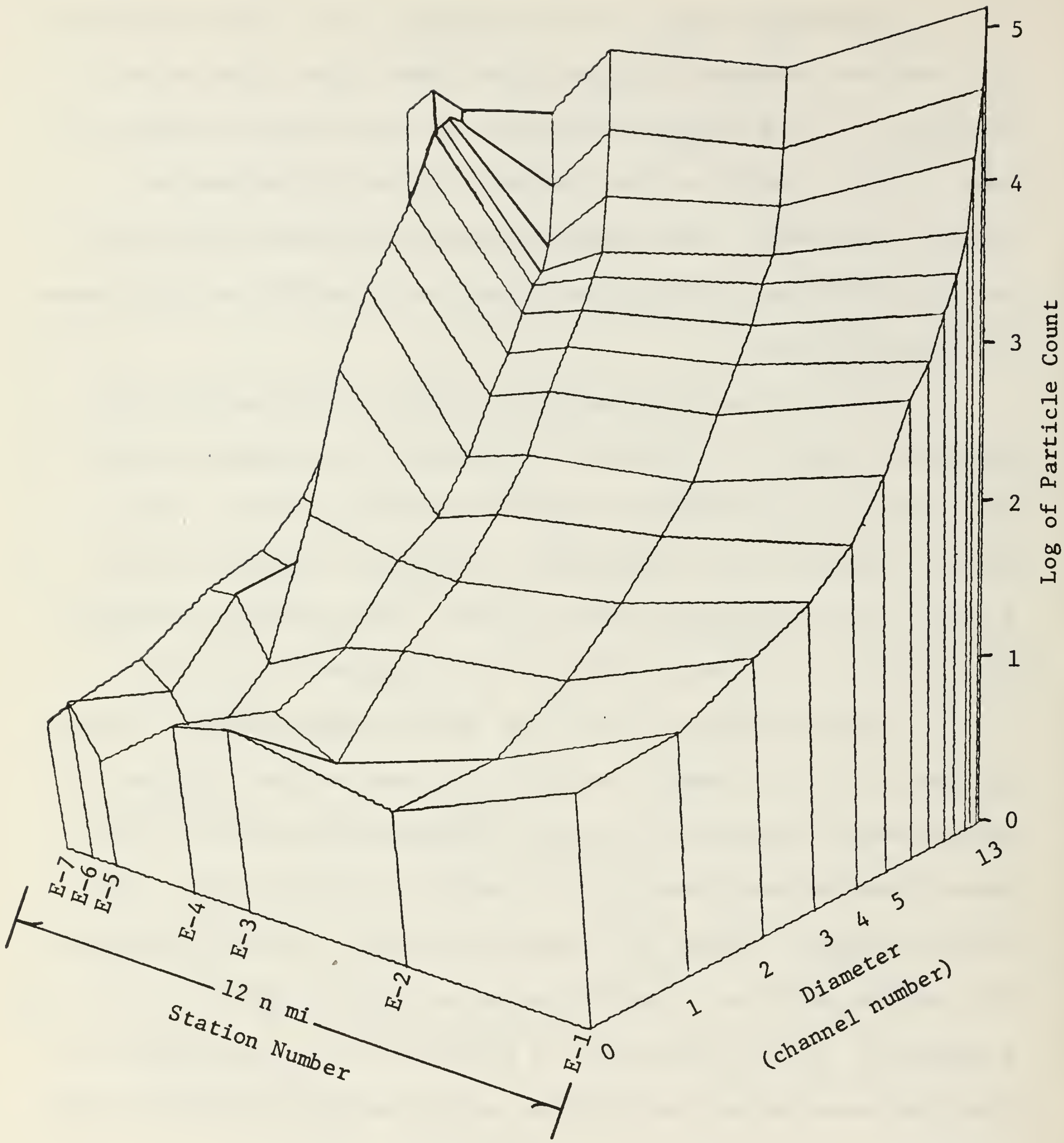

Figure 28. Type 4, Line E, 0 m, Cruise 14 to 17 January 1975

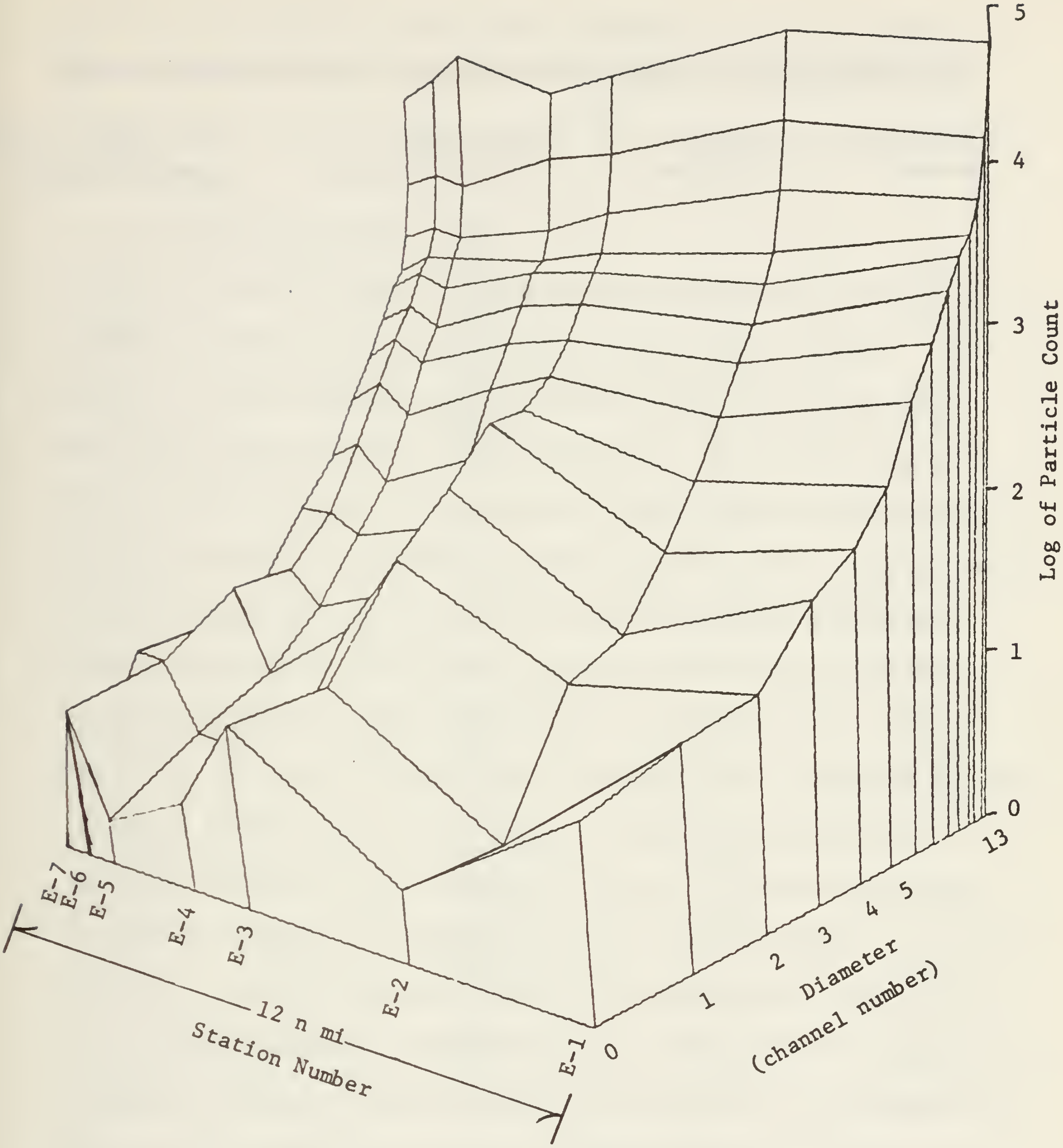

Figure 29. Type 4, Line E, 10 m, Cruise 14 to 17 January 1975

Observed C and K Values for Cruise 14 to 17 January 1975

Station Number	Depth (meters)	Slope (C) (count/micron)	K value ($x10^3$) (particles/ml)
A-1	30	3.08	113
A-2	0	3.00	145
A-3	0	2.36	91
	75	2.66	85
A-6	0	2.54	85
A-10	10	2.76	513
B-1	0	2.20	96
B-4	10	2.40	59
B-7	0	2.54	58
B-10	0	2.94	133
B-12	10	2.84	222
B-13	0	2.44	103
C-3	0	2.88	321
E-1	0	3.08	256
E-4	0	2.10	59
E-7	0	2.50	83
	30	4.50	2890
F-1	0	2.00	48
	30	4.48	1900
G-1	0	2.00	81
	30	2.62	277
G-4	0	2.36	112
G-5	0	2.36	102
G-7	0	2.64	76

Figure 30

x 10^3 particles/ml region with extremes as high as 2800 x 10^3 particles/ml. It is also to be noted that maximum values for K often appear below the surface at depths from 10 to 30 m.

3. <u>15 to 18 March 1974</u>

Figure 31 is a sketch of the horizontal profile of surface temperatures encountered during this cruise. An area of strong upwelling is centered just off Point Sur, but unfortunately only one particulate data station (C-1) was located in this area. Station data tables and the Type 1 graphs seem to indicate an even larger number (and volume) of particles were present during this upwelling period cruise than were indicated by the two previous northern cruises conducted during the Oceanic and Davidson Current Periods. As has been noted by Margalef [11], largest concentrations tend to be around rather than in the center of the most fertile (i.e. upwelled) spots. As was generally shown in the Type 1 graphs of the 27 to 31 October 73 cruise, the Type 1 graphs of this cruise also show that the thermocline is at a depth corresponding to the depths for diverging cumulative volume curves. XBT data confirm the thermocline location as generally varying between depths of 20 to 40 m. At the one station (C-1) centered in the upwelling region the water column was isothermal (9.2 to 9.5 °C) to the bottom (50 m).

Type 3 graphs were plotted for ten stations, E-10, E-15, E-20, E-25, E-30, B*25, G-15, G-20, G-25, and G-30.

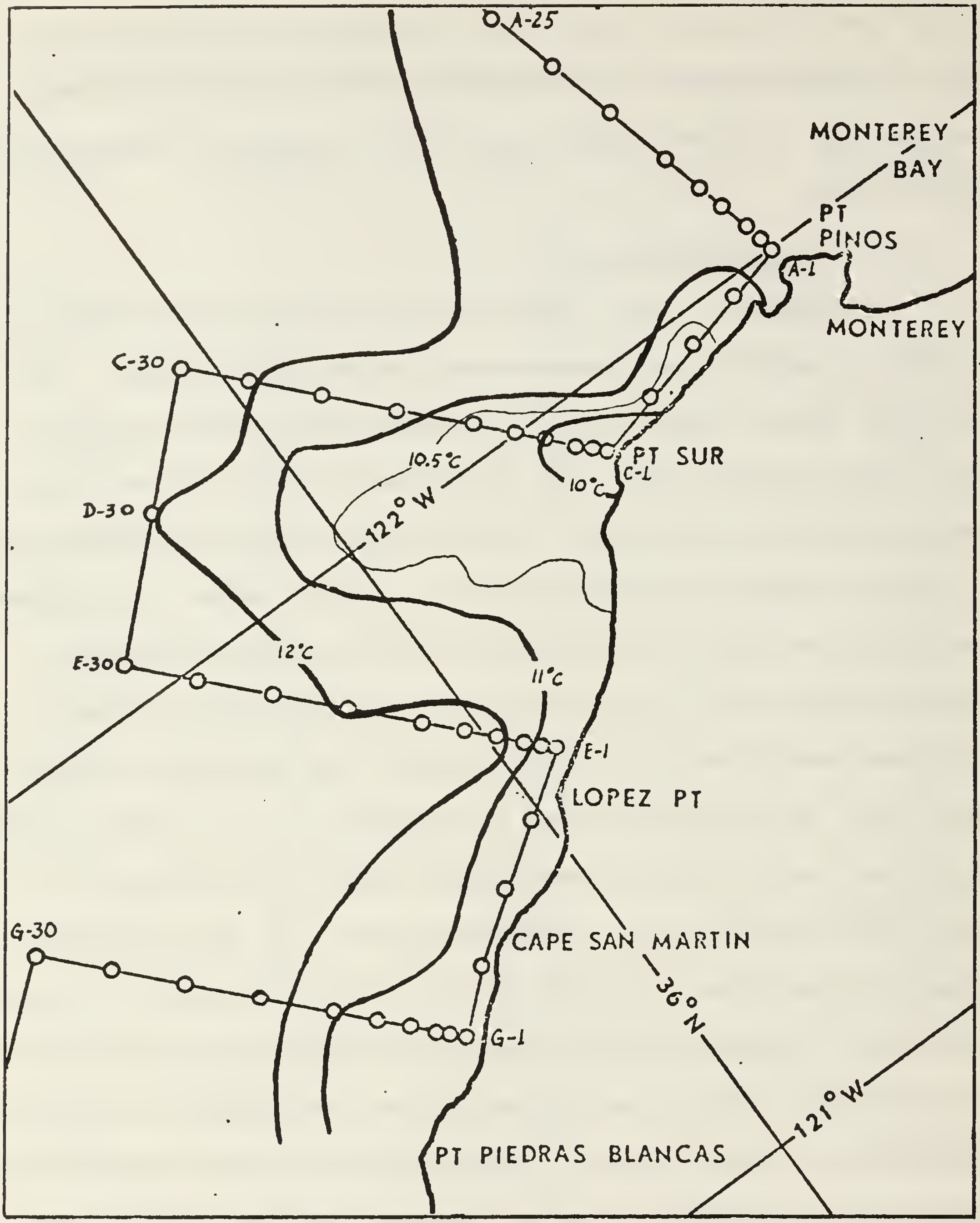

Figure 31. Horizontal Temperature Profile, Cruise 15 to 18 April 1974

In general these graphs agree quite closely with those presented for the October 1973 cruise. Large particle counts are indicated for the full size range of particles at depths which correspond to the pycnocline depth (Figures 32 and 33). As before the number of large particles per unit volume decreases with increasing depths. Counts for smaller diameter particles usually peak at or above the thermocline depth and are relatively constant below that level. High particle counts for large diameters indicated at shallow depths for stations G-20 and G-25 are probably indicative of a phytoplankton bloom (Figures 34, 35 and 36).

Figures 37, 38, 39 and 40 are Type 4 graphs for sections E and G for depths of 0 and 10 m. The most notable feature of these plots is the increased particle count in channel 0 (largest diameter). Every one of the stations at both depths for both sections illustrates an increase in the number of largest particles in channel 0 over the count for channel 1. This is quite opposed to the normal occurrence of particulate matter in the ocean and may have been caused by a large concentration of phytoplankton of a size very close to that of channel 0 existing in this oceanic section. Also of note is the generally stable particle count for each size range for all stations in the section. These are some of the most uniform spacial distributions encountered during any of the four cruises.

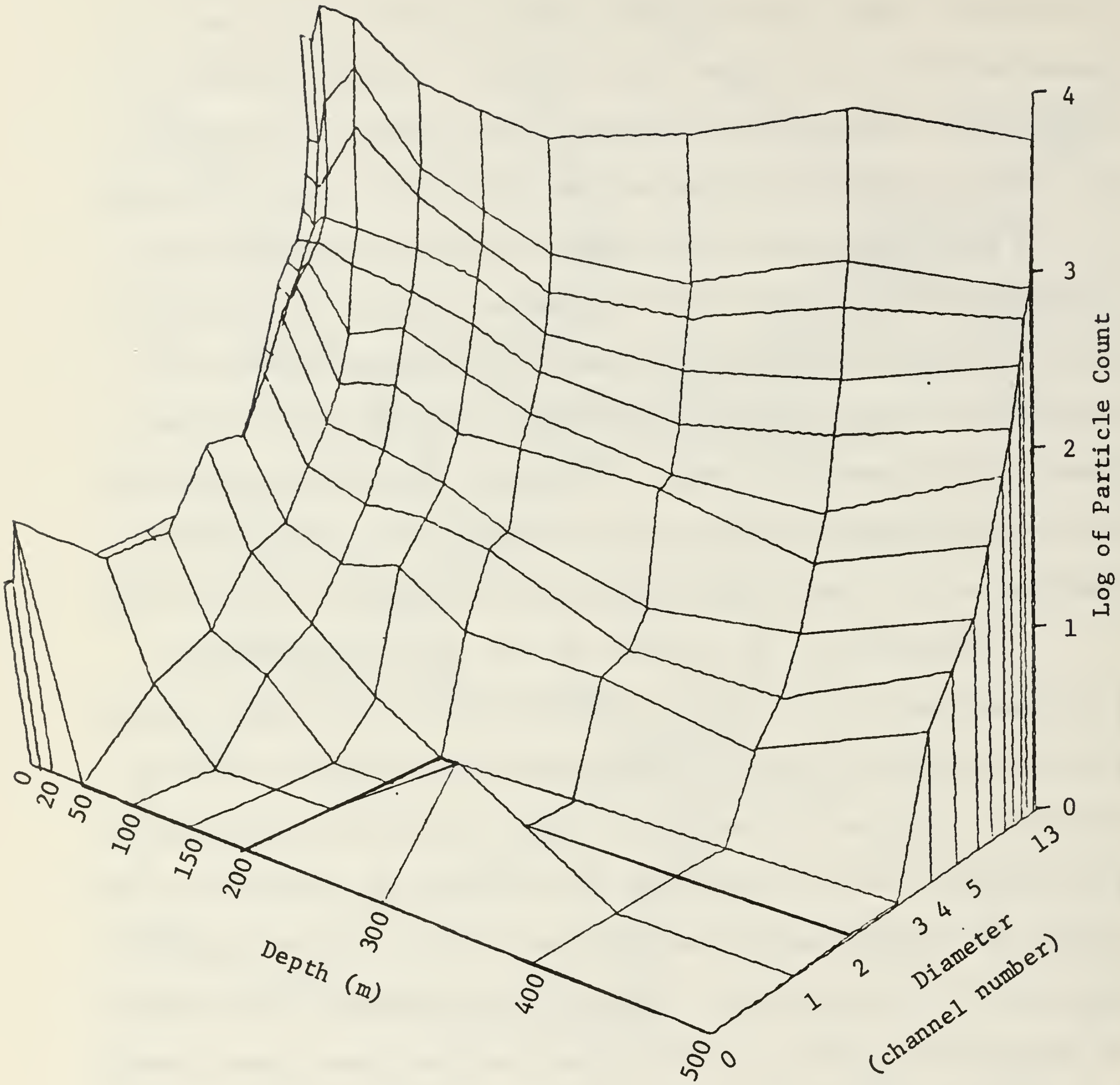

Figure 32. Type 3, Station E-10, Cruise 15 to 18 April 1974

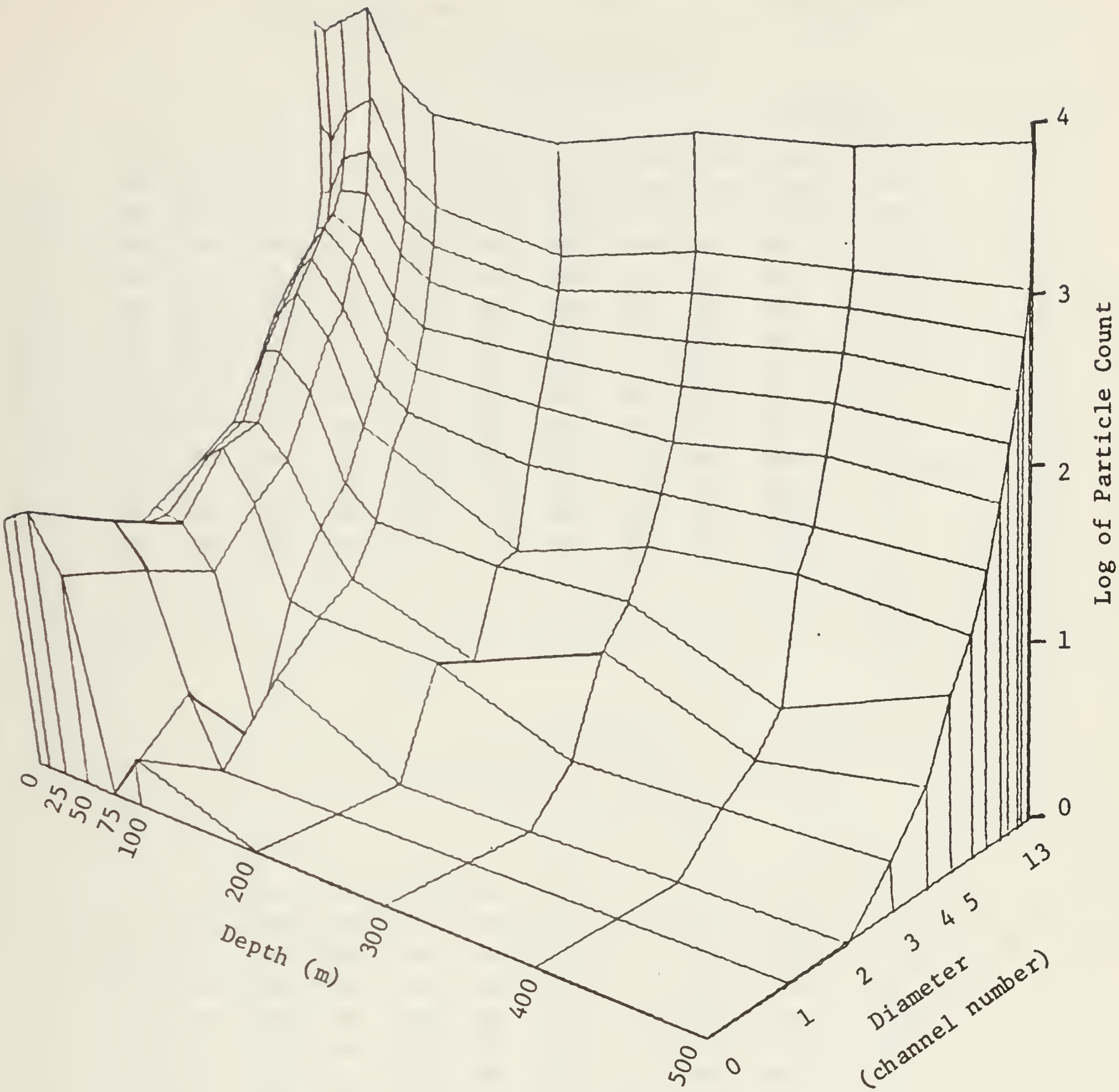

Figure 33. Type 3, Station B*25, Cruise 15 to 18 April 1974

COULTER COUNTER DATA SHIP R/V ACANIA

STATION G20 , 1745 HRS PDT, 35 DEG 32.8 MIN N, 121 DEG 39.8 MIN W, 18 APRIL 74

PARTICLE DIAMETERS IN MICRONS, VOLUMES IN CUBIC MICRONS PER 2ML SEAWATER SAMPLE

-PARTICLE COUNT- / -VOLUME PER COUNT-

DIA	CH#	0	10	20	50	100	150	200	300	400	500
SAMPLE DEPTH IN METERS		0	10	20	50	100	150	200	300	400	500
27.66	0	77 / 853715	60 / 665232	2097 / 23249872	7236 / 93227526	12 / 113872	2 / 22174	1 / 11087	1 / 11087	2 / 22174	8 / 88697
21.96	1	36 / 199569	47 / 260549	164 / 909151	584 / 3237465	14 / 77610	3 / 16633	0 / -----0	2 / 11087	3 / 16530	11 / 60979
17.43	2	36 / 99784	40 / 110872	113 / 313213	309 / 856487	19 / 52664	5 / 13859	3 / 8315	2 / 5543	10 / 27718	19 / 52664
13.83	3	49 / 67909	67 / 92855	113 / 156606	196 / 271636	36 / 49892	14 / 19402	4 / 5543	10 / 13859	12 / 16530	16 / 22174
10.98	4	59 / 40884	112 / 77610	168 / 116415	153 / 106021	36 / 24945	22 / 15244	5 / 3464	12 / 8315	30 / 20788	26 / 18016
8.71	5	160 / 55436	199 / 68948	378 / 130967	235 / 81421	142 / 49199	36 / 12473	15 / 5197	31 / 10740	33 / 11433	36 / 12473
6.92	6	488 / 84539	481 / 83327	625 / 108273	324 / 56129	423 / 73279	74 / 12819	52 / 9008	60 / 10394	52 / 9008	41 / 7102
5.49	7	976 / 84539	958 / 82980	831 / 71980	480 / 41577	632 / 54743	112 / 9701	86 / 7449	90 / 7795	116 / 10047	118 / 10221
4.36	8	1372 / 59420	1220 / 52837	1159 / 50195	1575 / 68212	956 / 41403	272 / 11783	197 / 8531	205 / 8878	204 / 8835	208 / 9008
3.46	9	1659 / 35925	1626 / 35210	4323 / 93613	3310 / 71677	1903 / 41208	574 / 12429	431 / 9333	383 / 8293	407 / 8813	444 / 9614
2.74	10	2562 / 27739	2650 / 28692	26924 / 291515	14900 / 161327	2819 / 30522	1083 / 11693	793 / 8586	748 / 8098	777 / 8412	805 / 8716
2.18	11	4423 / 23944	4531 / 24529	34118 / 184703	39879 / 215892	3201 / 17329	1856 / 10047	1480 / 8012	1415 / 7660	1423 / 7703	1524 / 8253
1.73	12	9866 / 26705	10481 / 28370	22107 / 59840	34030 / 92113	5179 / 14018	3218 / 8713	2462 / 6664	2324 / 6290	2616 / 7081	2617 / 7083
1.37	13	44539 / 60279	44129 / 59725	41674 / 56402	76808 / 103953	23738 / 32127	11571 / 15663	9656 / 13068	9876 / 13366	10449 / 14141	10480 / 14183
TOTAL VOL (CH 0-13) IN 2ML SW		1720387	1671736	25792736	85590960	659812	192621	104257	131405	189413	329180
UNCERT(±)		177064	175326	651797	1170357	93788	46514	25434	35524	48646	76904

COULTER COUNTER DATA SHIP R/V ACANIA

STATION G25 , 1553 HRS PDT, 35 DEG 29.7 MIN N, 121 DEG 44.5 MIN W, 18 APRIL 74

PARTICLE DIAMETERS IN MICRONS, VOLUMES IN CUBIC MICRONS PER 2ML SEAWATER SAMPLE

-PARTICLE COUNT- / -VOLUME PER COUNT-

DIA	CH#	0	10	20	50	100	150	200	300	400	500
SAMPLE DEPTH IN METERS		0	10	20	50	100	150	200	300	400	500
27.66	0	72 / 798279	74 / 820453	337 / 3736390	1169 / 12960949	538 / 5964919	0 / -----0	1 / 11087	2 / 22174	7 / 77610	1 / 11087
21.96	1	33 / 182938	24 / 133046	17 / 94241	81 / 449032	40 / 221744	5 / 27718	1 / 5543	1 / 5543	3 / 16630	0 / -----0
17.43	2	34 / 94241	28 / 77610	23 / 63751	77 / 213428	46 / 127502	3 / 8315	5 / 13859	6 / 16630	7 / 19402	1 / 2771
13.83	3	59 / 81768	31 / 42962	9 / 12473	124 / 171851	80 / 110872	7 / 9701	8 / 11087	20 / 27718	2 / 2771	2 / 2771
10.98	4	68 / 47120	63 / 43655	39 / 27025	197 / 136511	115 / 79689	15 / 10394	16 / 11087	30 / 20788	5 / 3464	6 / 4157
8.71	5	119 / 41230	178 / 61672	52 / 18016	426 / 147598	222 / 75917	27 / 9354	24 / 8315	35 / 12126	4 / 1385	9 / 3118
6.92	6	431 / 74665	411 / 71200	93 / 16111	813 / 140842	474 / 82114	57 / 9874	44 / 7622	43 / 7449	23 / 3984	34 / 5890
5.49	7	697 / 60373	744 / 64444	155 / 13425	893 / 77350	636 / 55089	113 / 9787	91 / 7882	92 / 7968	54 / 4677	57 / 4937
4.36	8	1026 / 44435	1582 / 68515	277 / 11996	1333 / 57731	953 / 41273	182 / 7882	174 / 7535	247 / 10697	109 / 4723	108 / 4677
3.46	9	1524 / 33001	2923 / 63296	725 / 15699	3356 / 72673	1185 / 25660	363 / 7863	369 / 7990	458 / 9917	224 / 4850	260 / 5630
2.74	10	2221 / 24047	5077 / 54970	1184 / 12819	8419 / 91155	1924 / 20831	749 / 8109	739 / 8001	829 / 8975	464 / 5023	455 / 4926
2.18	11	4587 / 24832	18134 / 98171	2791 / 15109	8493 / 45978	3577 / 19364	1232 / 6507	1304 / 7059	1675 / 9067	892 / 4818	783 / 4238
1.73	12	12551 / 33973	59269 / 160431	7127 / 19291	13344 / 36120	9547 / 25842	2042 / 5527	2322 / 6285	3230 / 8743	1476 / 3995	1461 / 3954
1.37	13	62348 / 84382	365035 / 494045	14816 / 20052	49848 / 67465	42933 / 58106	8003 / 10827	8895 / 12038	12490 / 16904	7703 / 10425	7408 / 10026
TOTAL VOL (CH 0-13) IN 2ML SW		1625284	2254470	4076398	14668683	6909922	131855	125390	184699	163754	68182
UNCERT(±)		171853	166777	255765	498068	345389	29293	34921	43996	53324	21615

Figure 34. Station Data Tables (from Reference 6)

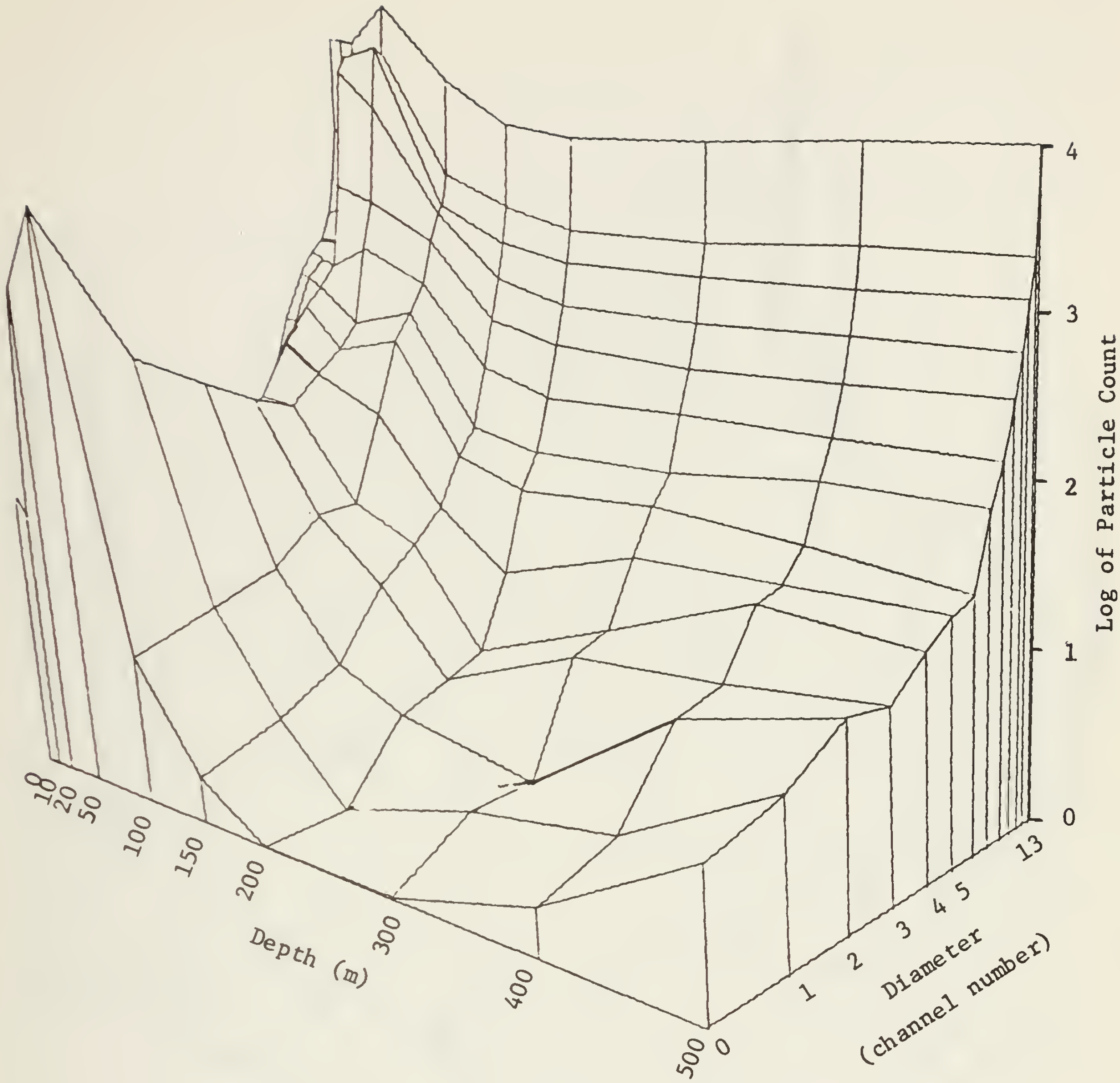

Figure 35. Type 3, Station G-20, Cruise 15 to 18 April 1974

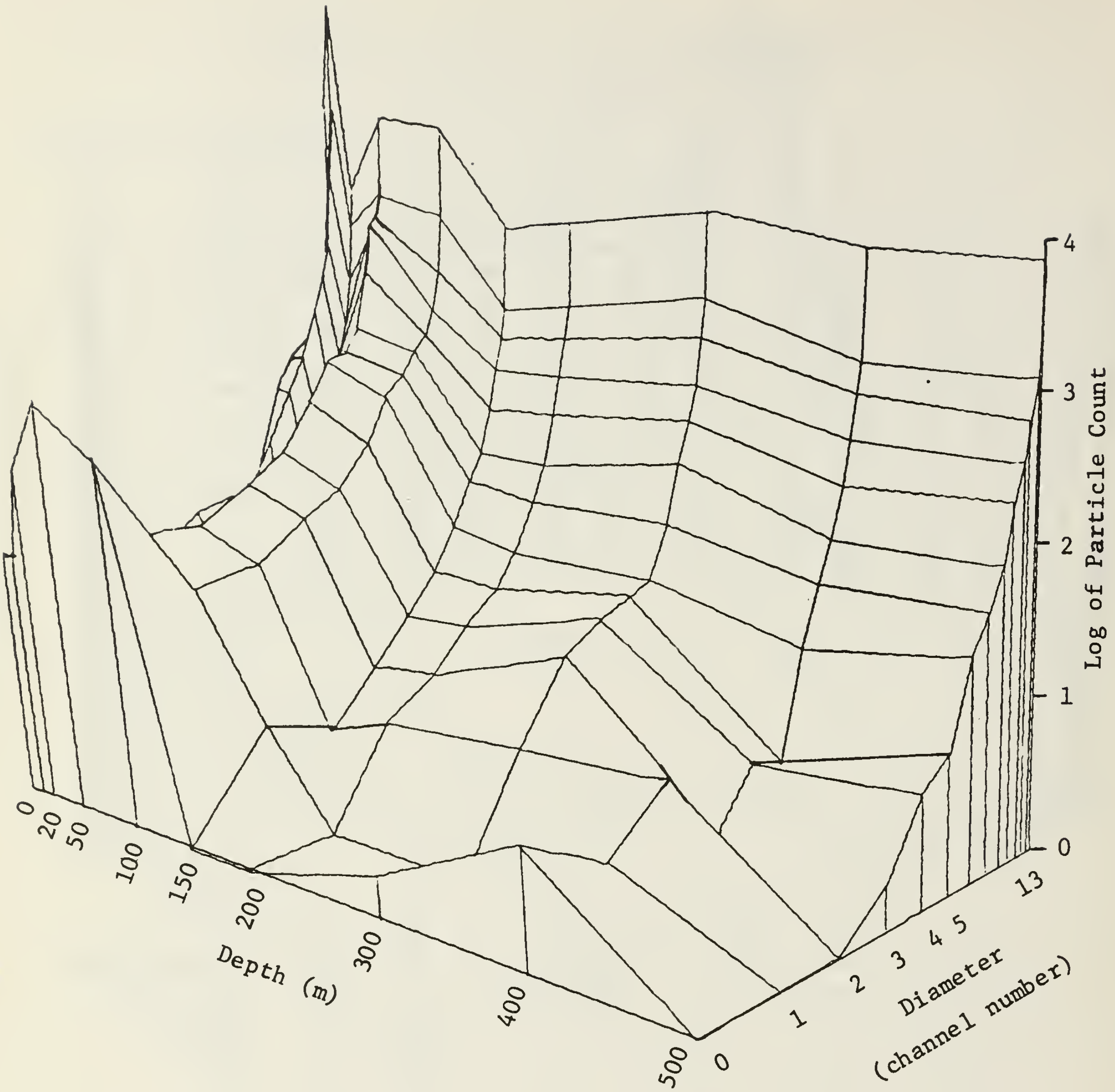

Figure 36. Type 3, Station G-25, Cruise 15 to 18 April 1974

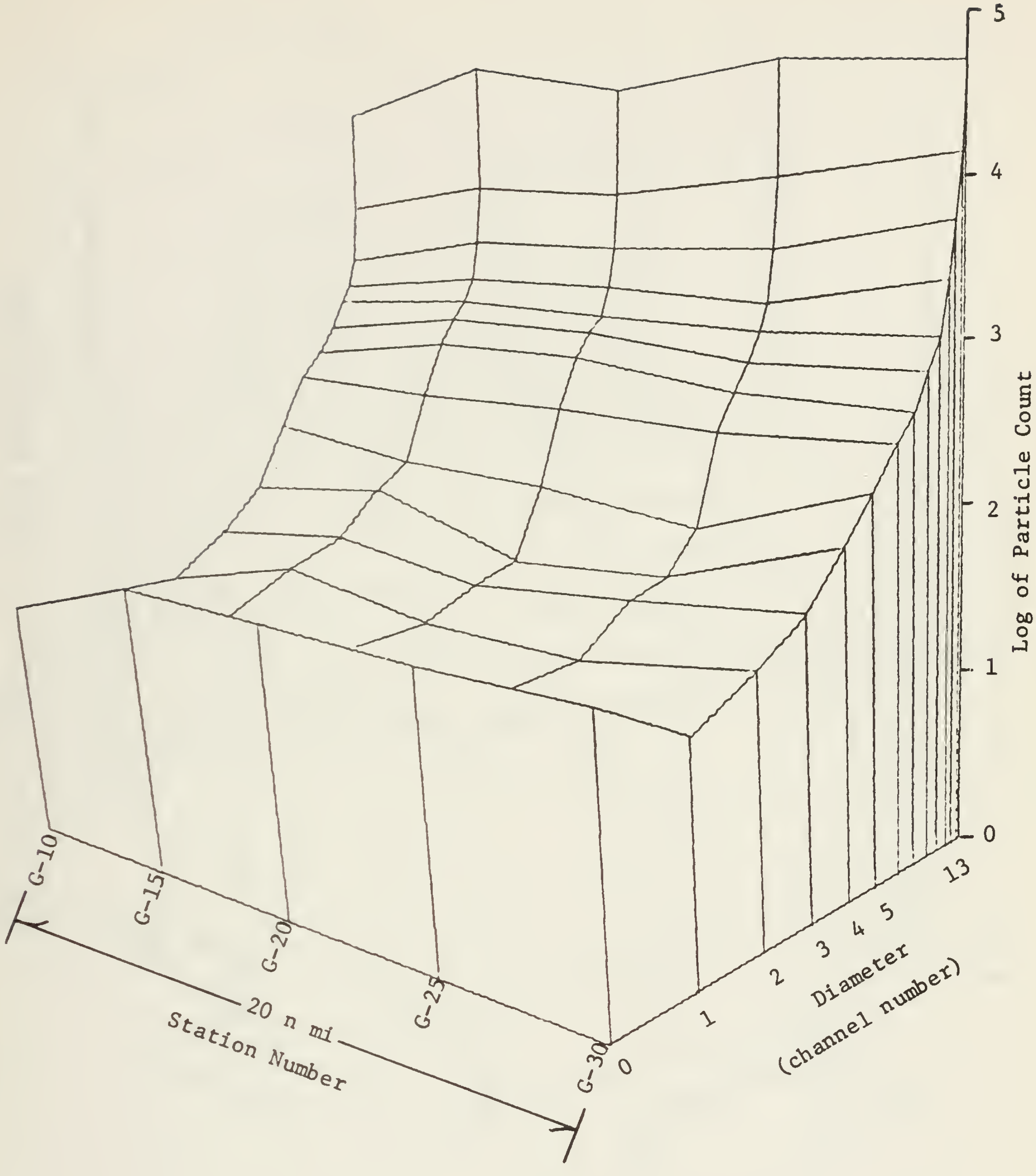

Figure 37. Type 4, Line G, 0 m, Cruise 15 to 18 April 1974

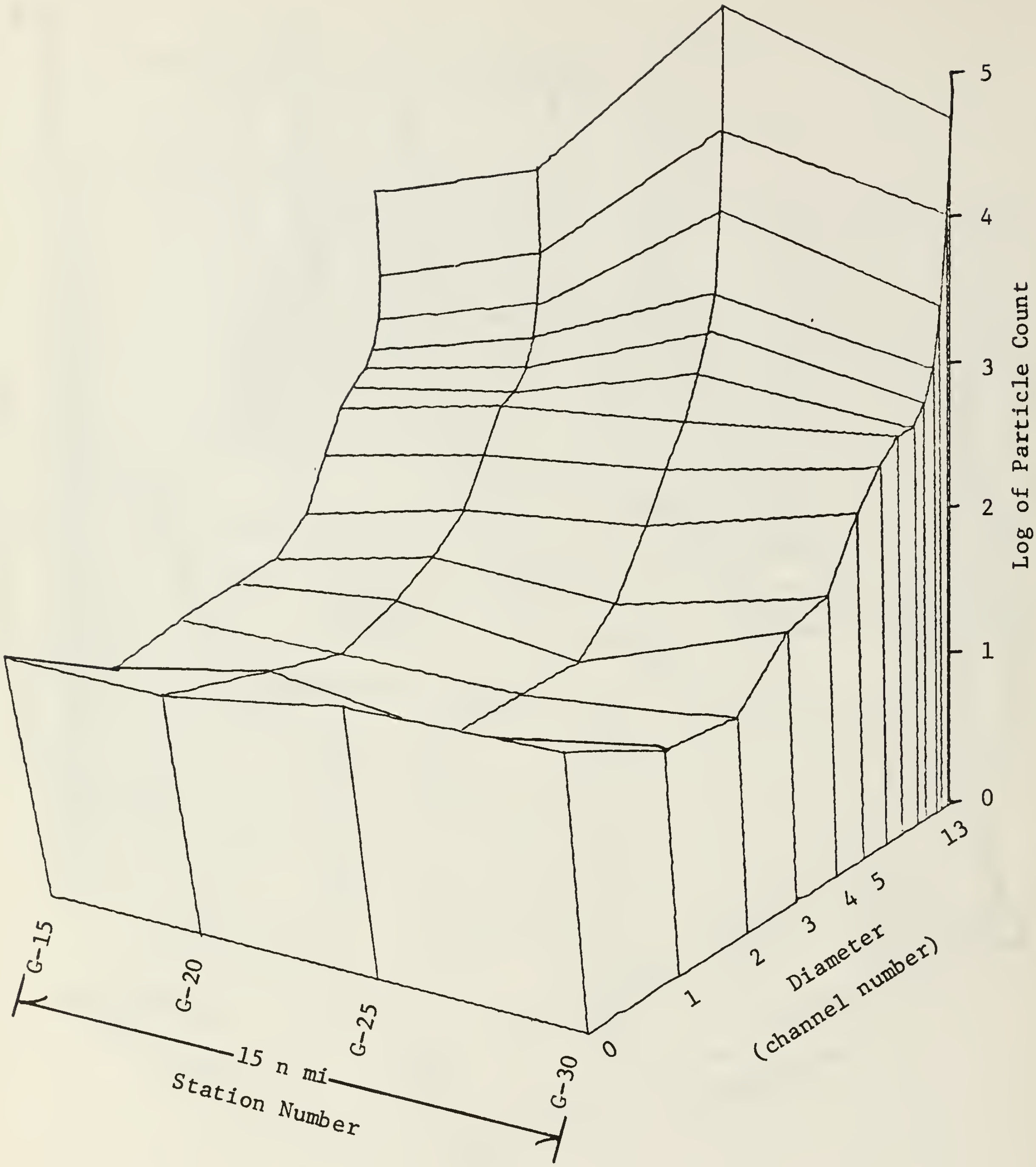

Figure 38. Type 4, Line G, 10 m, Cruise 15 to 18 April 1974

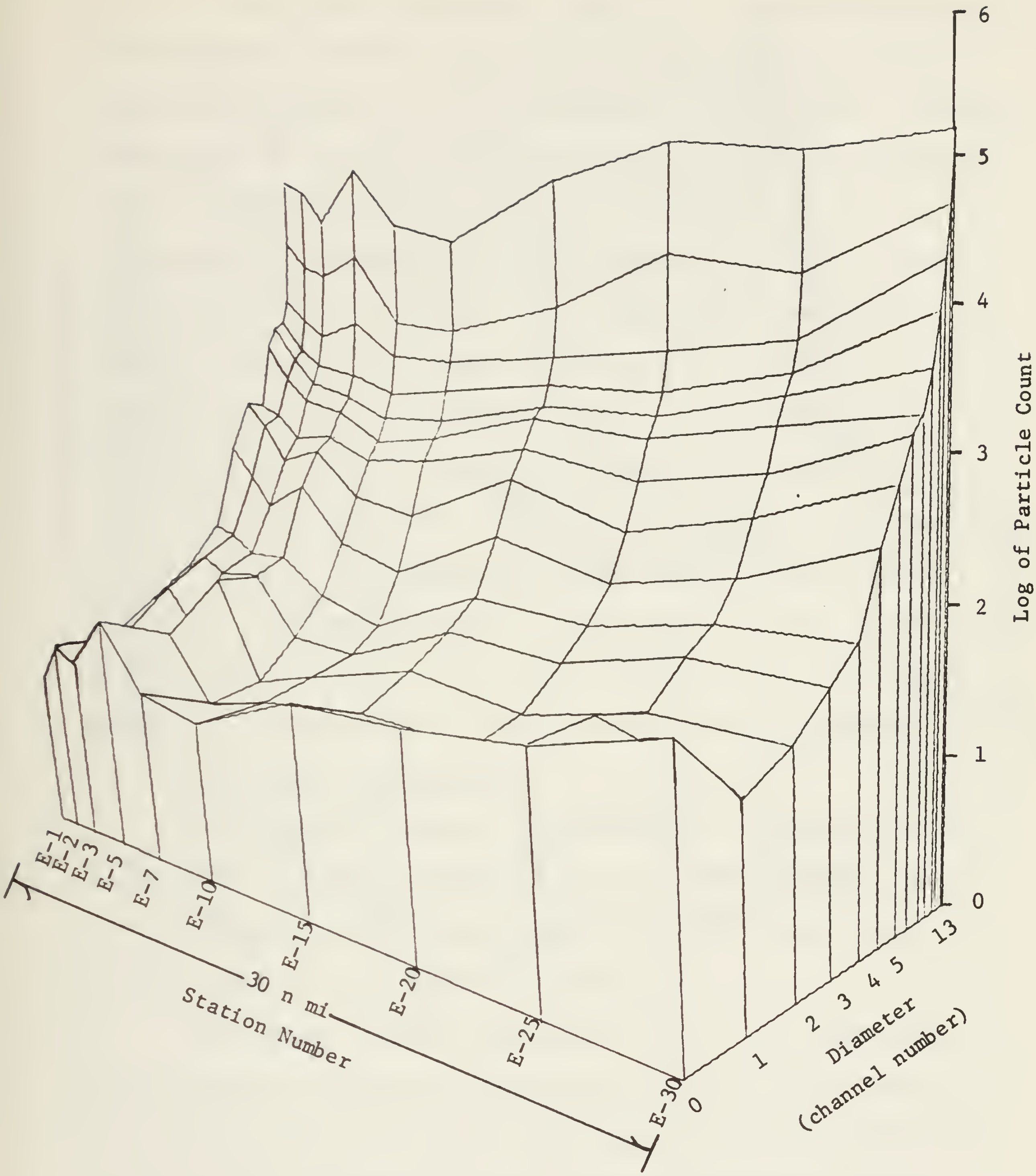

Figure 39. Type 4, Line E, 0 m, Cruise 15 to 18 April 1974

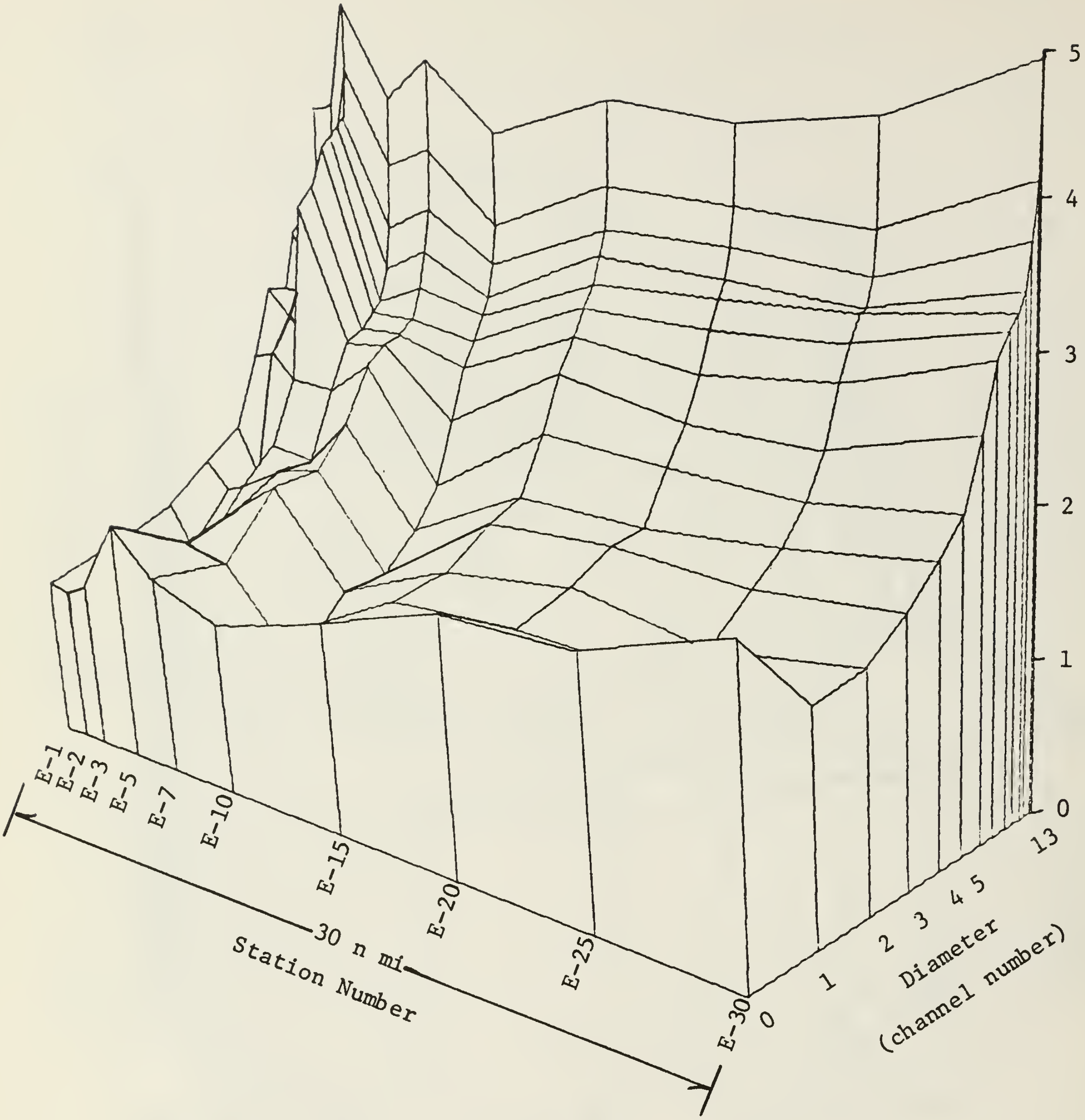

Figure 40. Type 4, Line E, 10 m, Cruise 14 to 18 April 1974

The table of observed values of C and K is presented as Figure 41. These values probably represent the most distinctive feature of this upwelling period cruise. Values for C were the lowest encountered for any cruise with 50% of them falling in the 1.58 to 2.28 range. All but one of the remaining values fell in the range observed by Gordon [7] (i.e. from 2.4 to 3.1). At 11 stations two values were computed for C, and in every instance but one (station C-15) the shallow water values were in the 1.58 to 2.28 range, and the deep water values were in the 2.4 to 3.1 range.

This cruise also exhibited the lowest average values for K. Ninety-three per cent of the values fell between 10 and 73 x 10^3 particles/ml. The highest value of 137 x 10^3 particles/ml was far below the previous maxima. As noted before K values showed a definite decrease with depth.

4. <u>17 to 21 January 1975</u>

Prevailing oceanic conditions for this cruise were found to be unaltered from the 14 to 17 January 1975 cruise. A deep mixed layer at approximately 11.5 °C was present at all stations to a depth of at least 50 m.

The Type 1 graphs generally follow the horizontal line-constant volume hypothesis for all but the largest particles (which may not be represented by a statistically accurate count anyway). High particle counts are still indicated by the data tables, but overall levels appear to be somewhat less than those of the previous Upwelling Period

Observed C and K Values for Cruise 15 to 18 April 1974

Station Number	Depth (meters)	Slope (C) (count/micron)	K Value ($x10^3$) (particles/ml)
B*1	0	2.04	64
B*2	0	1.94	73
	45	2.20	30
B*5	0	1.72	70
	70	3.00	34
B*7	0	1.58	64
	20	2.56	53
B*25	0	1.88	20
	100	3.04	16
E-1	0	1.80	67
E-5	0	1.90	24
	200	2.64	18
E-10	0	2.54	32
E-15	0	2.10	42
	200	3.80	41
E-20	0	2.40	53
	300	3.06	23
E-25	0	2.76	124
E-30	0	2.50	137
G-10	0	1.74	25
	100	2.16	25
G-15	0	2.14	44
	400	2.78	21
G-20	0	2.16	42
	400	2.82	14
G-25	20	2.86	19
G-30	0	2.28	38
	400	3.00	10

Figure 41

cruise. At several stations anomalously high particle counts were observed at relatively great depths (A-5 at 300 m, A-7 at 100 and 300 m, A-20 at 1000 m, A-30 at 300 m, C-10 at 200 and 400 m, C-15 at 200 and 400 m, C-20 at 200 m and E-2 at 100 m), but close observation of the vertical profiles of dissolved oxygen, salinity, density, temperature, phosphate and silicate as well as water depth failed to reveal any plausible explanation for these occurrences.

Graphs for particle distribution with depth (Type 3) were plotted for stations A-10, A-15, A-20, A-30, C-10, C-15, C-20, C-25, C-30, E-10, E-15, E-20, E-25, and E-30. Five of these graphs illustrate the large count anomaly already discussed (Figures 42 and 43). The remaining graphs show characteristics very similar to those for the 14 to 17 January 1975 cruise. One significant difference was noted in the STD records; all deep water stations (bottom depth exceeding 100 m) for this southern cruise displayed a salinity minimum at the surface which remained constant and extended to a depth of 50 m. As noted for the 14 to 17 January northern cruise this condition sets up a density trap where large numbers of various sized particles may collect. All the Type 3 graphs for the 17 to 21 January cruise illustrate this phenomenon. Most of the stations (excluding those with anomalous spikes) continue to indicate a fall-off in the count for larger particle sizes (channels 0 and 1) at depths below the mixed layer.

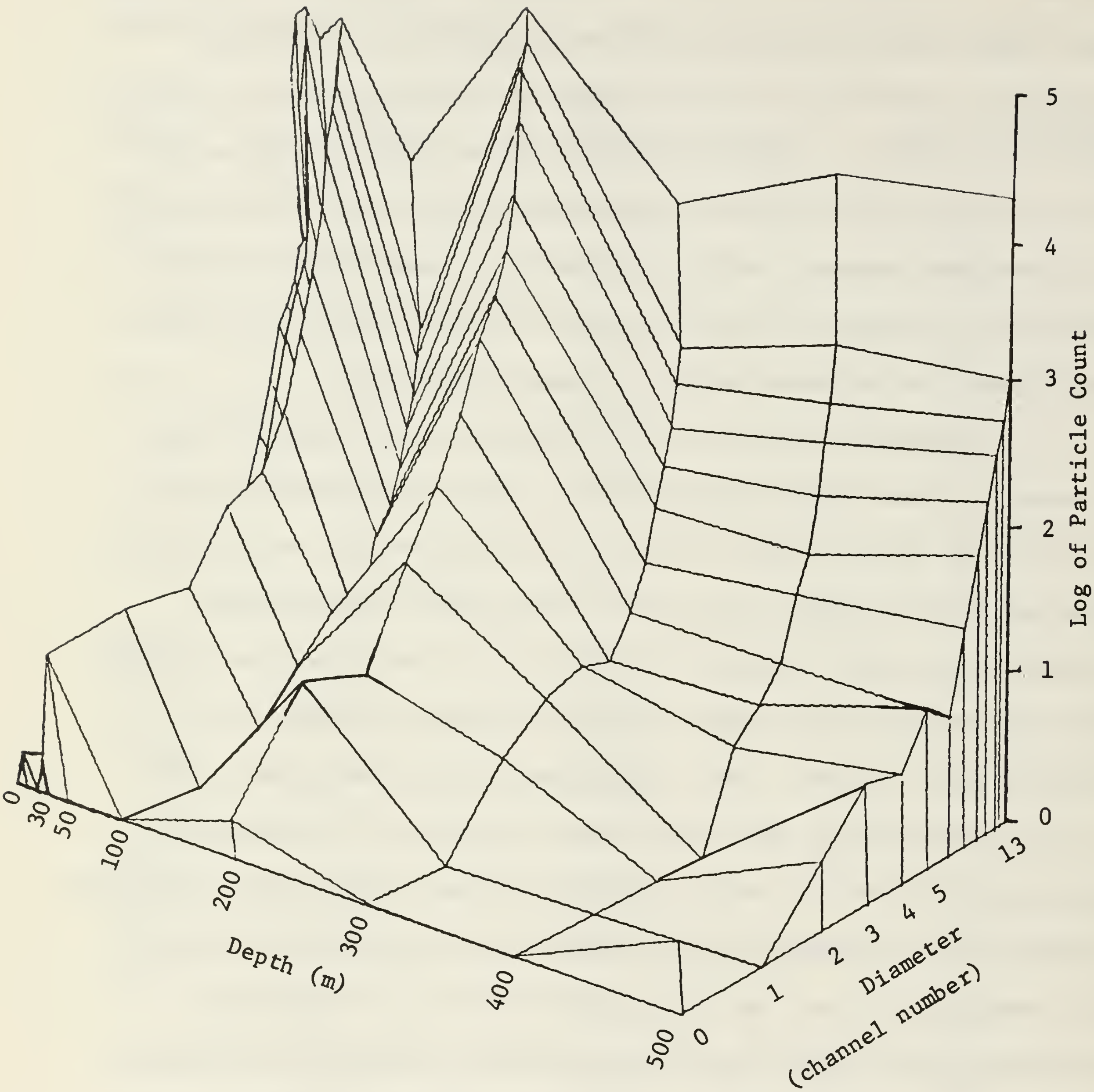

Figure 42. Type 3, Station C-20, Cruise 17 to 21 January 1975

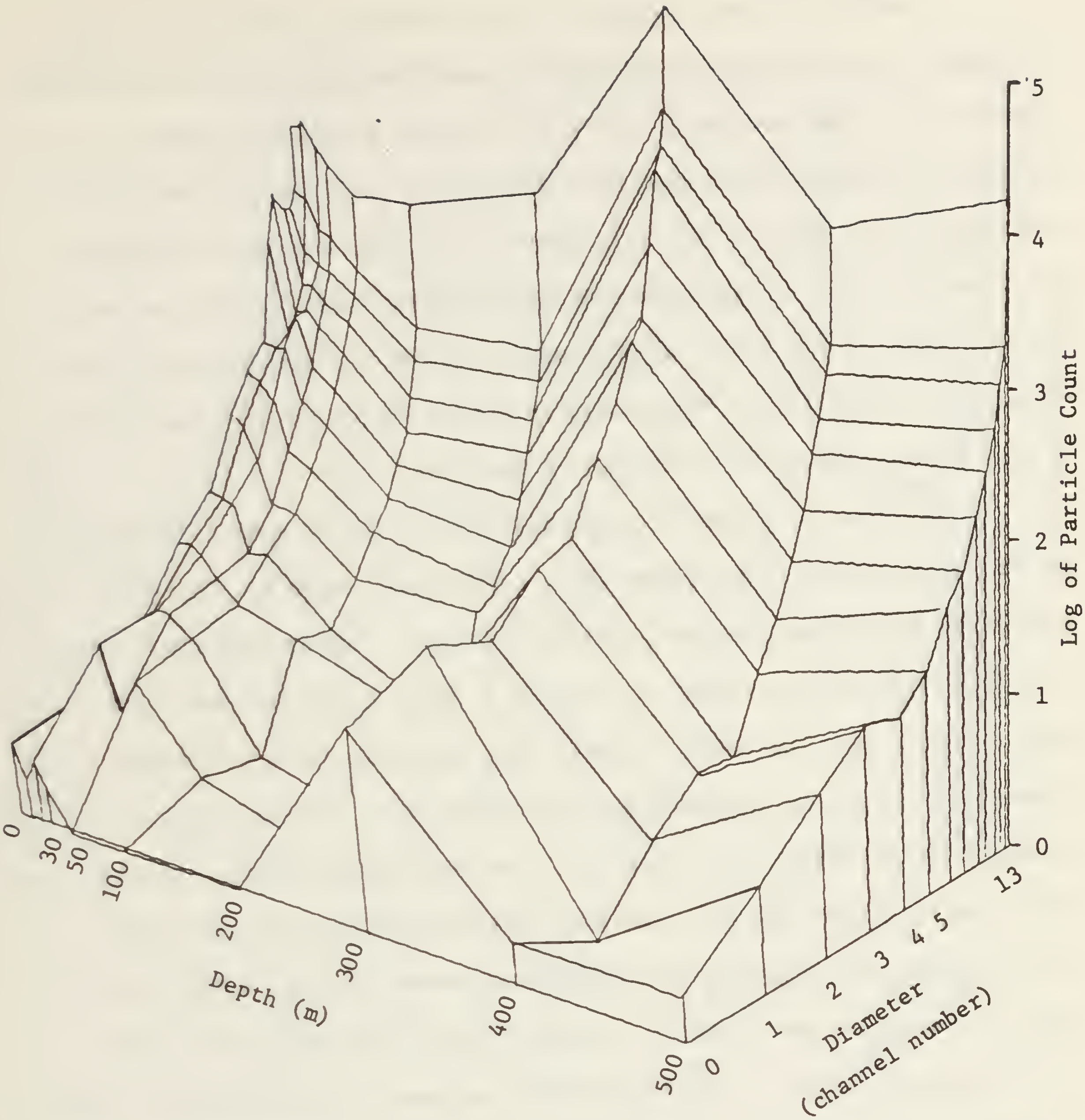

Figure 43. Type 3, Station A-30, Cruise 17 to 21 January 1975

Section plots (Type 4) for station lines A, C, and E appear to show fairly uniform distributions at all stations along the lines except at C-15. Unlike possible phytoplankton blooms indicated for channel 0 at the surface for stations C-1, C-2, C-7, E-5, and E-15, the elevated counts at station C-15 extend across the entire size spectrum and do not appear to be a result of a change in any physical or chemical property of the water. Surface plots for sections C and E are shown in Figures 44 and 45.

Tables of observed values for C and K are included as Figure 46 and are comparable to those computed for the previous Davidson Current Period cruise. Approximately 60% of the C values occurred in the 2.4 to 3.1 range, and the majority of the varient values were only slightly outside these limits. As was previously observed, values for C seemed to increase with depth. Two extremely large values for C were observed for the surface for stations C-15 and E-5. These correspond to localized areas having very large particle counts and led to values for K in excess of 1800 $\times 10^3$ particles/ml. Shallow water values for K normally fell in the 39 to 276 $\times 10^3$ particles/ml range, while values for depths exceeding 100 m ranged from 8 to 28 $\times 10^3$ particles/ml for all stations except A-20 (at 400 m). Very low values for K in the 8 to 11 $\times 10^3$ particles/ml range which occurred at great depth may be indicative of the background value that can be expected for the area.

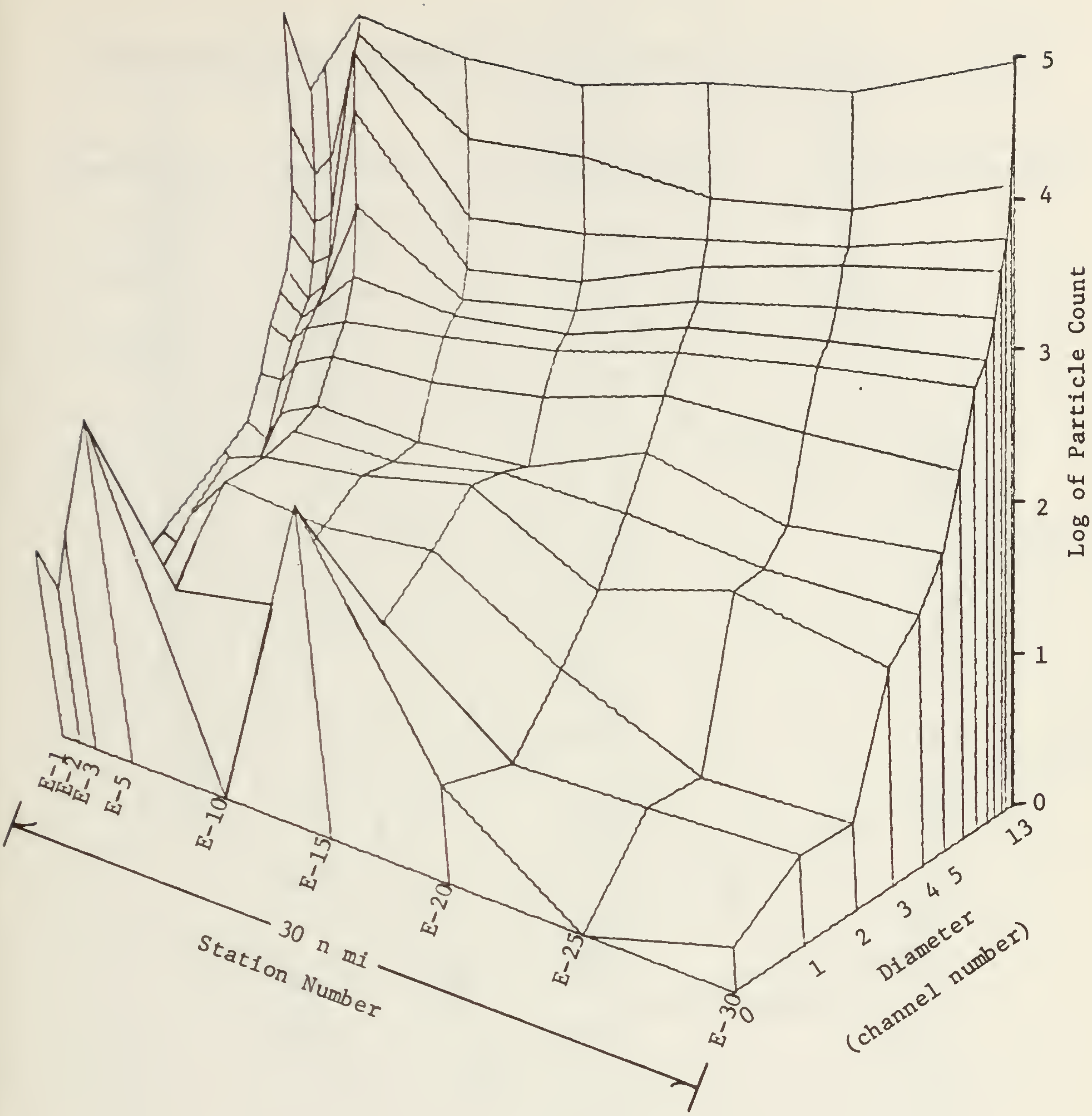

Figure 44. Type 4, Line E, 0 m, Cruise 17 to 21 January 1975

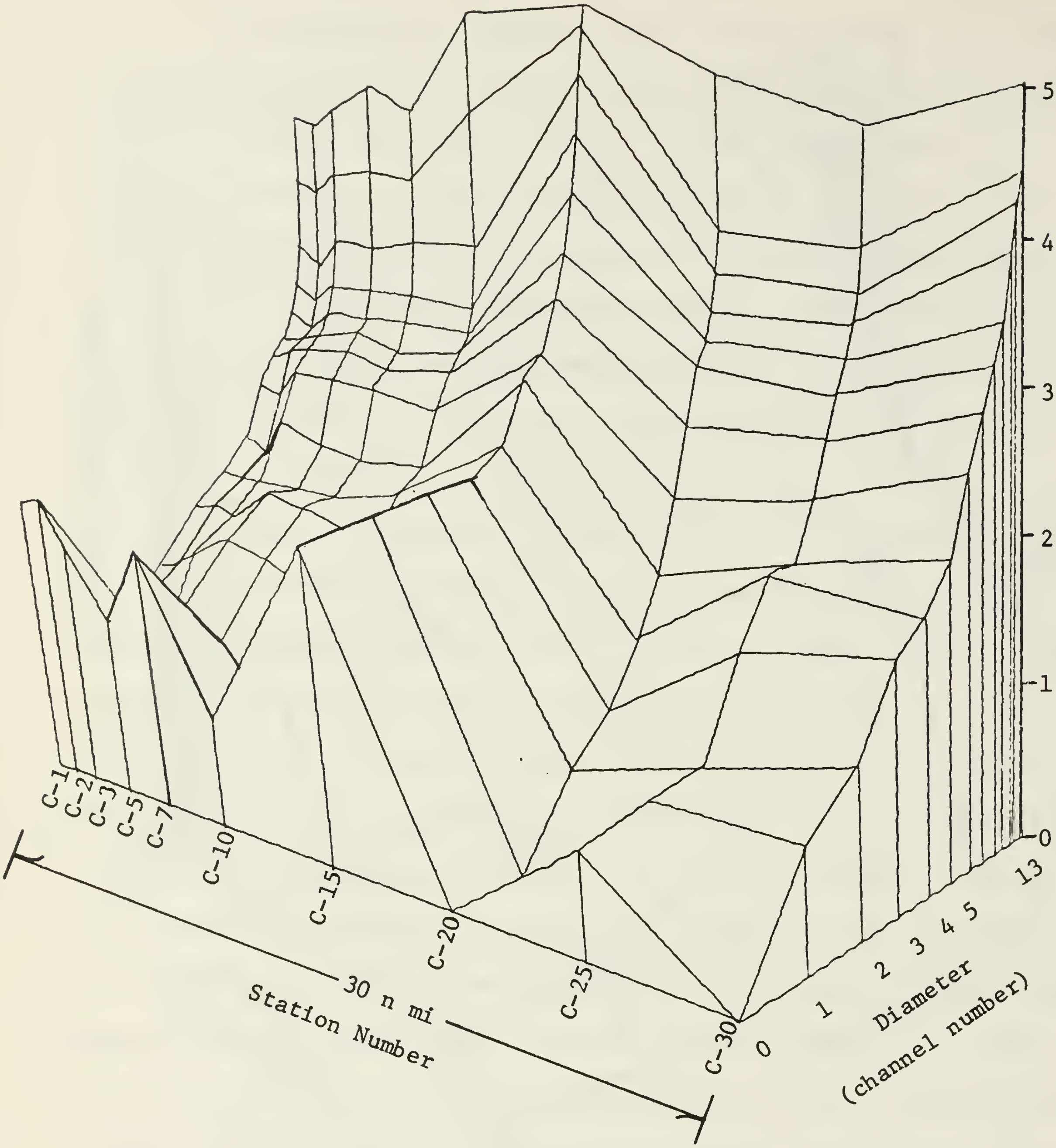

Figure 45. Type 4, Line C, 0 m, Cruise 17 to 21 January 1975

Observed C and K Values for Cruise 17 to 21 January 1975

Station Number	Depth (meters)	Slope (C) (count/micron)	K Values ($x10^3$) (particles/ml)
A-30	30	2.74	57
A-25	0	2.76	123
	400	3.28	18
A-20	0	2.48	67
	400	3.86	85
A-15	100	3.00	26
A-10	0	2.00	74
	300	3.16	26
A-7	0	2.44	76
A-5	0	2.66	101
A-1	0	2.84	200
B-1	10	2.76	164
C-1	0	2.24	72
C-5	20	3.00	64
C-7	0	2.36	39
	200	2.74	11
C-10	0	2.34	43
	300	3.16	15
C-15	0	3.80	1836
C-20	0	3.20	79
	400	3.20	8
C-25	0	2.96	86
C-30	0	3.32	276
D-30	0	2.28	56
E-25	50	2.96	32
E-20	0	2.20	49
	200	2.80	10
E-15	100	2.80	9

Figure 46

Station Number	Depth (meters)	Slope (C) (count/micron)	K Values ($x10^3$) (particles/ml)
E-10	0	2.72	74
	50	2.72	30
E-5	0	4.80	1933
	30	3.00	51
E-1	20	3.34	442
F-2	0	2.70	50
G-1	0	2.70	65

Figure 46 (Cont'd)

V. CONCLUSIONS

This study has provided detailed information on the occurrence and distribution of suspended particulate matter along the California coast. The identification of small-scale temporal and spacial variations of particle distributions was made possible through the use of a relatively fine-spaced station grid and by collection of data during several oceanic seasons.

Pycnoclines occurring during oceanic periods provided "traps" where particles of all sizes collected. When a deep mixed layer was present particle concentrations were randomly distributed in the layer.

It was also noted that concentrations and counts for larger size particles exhibit a definite fall-off with depth, but both appear to be constant throughout the water column for small size particles. At almost all stations particle counts appeared to approach stable "background" levels at depths in excess of 200 m.

Because of the fertile waters along the central coast it is not surprising particle counts were generally higher than previously reported by Gordon for the Sargasso Sea [7].

Particle sizes and distributions also reflected bottom topography and water depth. Shallow water stations were found to have higher particle concentrations, especially noticeable for larger diameter particles, than deep water stations. Smaller particle counts along the entire range of particle sizes were observed at stations over the Monterey Submarine Canyon during the 27 to 31 October 1973 cruise. During the 14 to 17 January 1975 cruise this condition was not observed and may have been altered by river discharges.

Observations during the Upwelling Period indicated that increased particle concentrations occurred around the periphery of the upwelled area rather than in the center.

Localized areas of extremely high particle counts were believed to be the result of phytoplankton "blooms", but a species identification was not conducted.

Three-dimensional isometric graphs of the logarithm of the number of particles counted as a function of the particle diameter and depth (Type 3) provide a method to depict the distribution of particulate matter vertically in the water column. A further refinement of the computer program which plots these graphs [13] to permit the particle counts (the vertical axis) for all stations to be plotted on the same scale would provide an excellent tool which would allow a quick visual comparison of particle distributions. The comparison of distributions for adjacent stations, or for the same station at different times, for various oceanic periods will clearly show patterns of spacial and temporal variation.

In a second three-dimensional type of graph the logarithms of the number of particles counted are plotted as functions of the particle diameter and the station locations. This Type 4 graph provides a visual display of the horizontal distribution of particulate matter for lines of stations or sections at any given depth. This is valuable for studies of the variations of horizontal particle distributions, but more sectors from the same areas and different time periods must be completed before patterns can be clearly established.

Data were assumed to follow a Junge type distribution of the form $M_i = K'D_i^{-C}$, where M_i = count and D_i is the mean diameter in Coulter counter channel i and $K' = K(1-2^{-C/3})$. Values for C were similar to those found by Gordon, but K values were considerably higher with much higher but localized values noted during the Davidson Current period for some stations. The lowest average values for both C and K were noted during the Upwelling Period. The values for K show a definite decrease with depth, often tending to background values for depths in excess of 200 m.

APPENDIX

Sample Computer Programs

```
//DIDDS2B JOB (2219,0648,OS42),'DIDDLEMEYER',TIME=2
// EXEC FORTCLGP,REGION.GO=100K
//FORT.SYSIN DD *
      COMMON VOLCH(13,14)
      INTEGER BOTNO,DEPTH,PART,TIME,SUM,VOLCH,STAT,LATDEG,LATMIN,
     1LONDEG,LONMIN,DATE1,DATE2,DATE3,CTIME,SHIP1,SHIP2,SHIP3,SHIP4,
     2SHIP5,SHIP6,SHIP7
      DIMENSION BOTNO(13),DEPTH(13),CTIME(13),PART(13,14),SUM(13)
      INTEGER BSUM,UNCERT
      DIMENSION BSUM(13),UNCERT(14)
      DIMENSION TVOLCH(14),TVCLOG(14)
      DIMENSION SSUM(13)
      REAL*8 DASH(13)/13*'______  '/
   15 CONTINUE
      VOL=11424.8
      DIA=2.0*((3.0*VOL)/(4.0*3.14159))**.33333
      READ(5,5,END=915) NUMPTS
    5 FORMAT (I2)
      READ(5,6)SHIP1,SHIP2,SHIP3,SHIP4,SHIP5,SHIP6,SHIP7
    6 FORMAT(7A4)
      DO 30 I=1,NUMPTS
      READ(5,10) BOTNO(I),DEPTH(I),CTIME(I),(PART(I,J),J=1,8)
   10 FORMAT(I2,1X,10(I6,1X))
      READ(5,20) (PART(I,J),J=9,14)
   20 FORMAT(T18,6(I6,1X))
   30 CONTINUE
      WRITE(6,111)
  111 FORMAT('1',1X,'COULTER COUNTER DATA',6X,'SHIP')
      WRITE(6,113)SHIP1,SHIP2,SHIP3,SHIP4,SHIP5,SHIP6,SHIP7
  113 FORMAT('+',32X,7A4)
      WRITE(6,112)
  112 FORMAT(/5X,'STATION',7X,',',6X,'HRS PST,',4X'DEG',6X,'MIN N,',5X
     1'DEG',6X,'MIN W,')
   26 READ(5,27)STAT,LATDEG,LATMIN,LONDEG,LONMIN,TIME,DATE1,DATE2,DATE3
   27 FORMAT(1A4,2X,1A2,1X,1A4,3X,1A3,1X,1A4,2X,1A4,5X,1A2,1A3,1X,1A2)
   28 WRITE(6,29)STAT,TIME,LATDEG,LATMIN,LONDEG,LONMIN,DATE1,DATE2,DATE3
   29 FORMAT('+',13X,1A4,3X,1A4,10X,1A2,5X,1A4,8X,1A3,5X,1A4,10X,1A2,1X,
     11A3,1X,1A2)
      WRITE(6,333)
  333 FORMAT(//5X,'PARTICLE DIAMETERS IN MICRONS, VOLUMES IN CUBIC MICRO
     1NS PER 2ML SEAWATER SAMPLE')
      WRITE(6,999)
  999 FORMAT(//,26X,'P A R T I C L E  C O U N T')
      WRITE(6,1000)
 1000 FORMAT('+',23X,'________________________________')
      WRITE(6,1001)
 1001 FORMAT(25X,'V O L U M E  P E R  C O U N T')
  666 WRITE(6,777)
```

Program producing Data Table printout (CONTINUED)

```
  777 FORMAT(/,5X,'SAMPLE DEPTH')
      WRITE(6,888)
  888 FORMAT(5X,'IN METERS')
  555 WRITE(6,444) (DEPTH(I),I=1,NUMPTS)
  444 FORMAT('+',14X,13(I4,5X))
      WRITE(6,222)
  222 FORMAT (//2X,'DIA',2X,'CH#')
  916 CALL VOLCAL(PART,SUM,NUMPTS,BSUM)
      INT=0
      J=14
  901 CONTINUE
      WRITE(6,900)DIA,INT
  900 FORMAT(' ',F5.2,I3)
      WRITE(6,911) (PART(I,J),I=1,NUMPTS)
  911 FORMAT('+',13X,13(I6,3X))
  913 CONTINUE
      WRITE(6,1002) (DASH(I),I=1,NUMPTS)
 1002 FORMAT('+',13X,13(1A8,1X))
      WRITE(6,910) (VOLCH(I,J),I=1,NUMPTS)
  910 FORMAT(12X,13(I8,1X))
      WRITE(6,912)
  912 FORMAT(' ')
  905 CONTINUE
      INT=INT+1
      J=J-1
      VOL=VOL/2.0
      DIA=2.0*((3.0*VOL)/(4.0*3.14159))**.33333
      IF(J.GT.0) GO TO 901
      WRITE(6,922)
  922 FORMAT(//,1X,'TOTAL VOL')
      WRITE(6,923)
  923 FORMAT(1X,'(CH 0-13)')
      WRITE(6,924)(SUM(I),I=1,NUMPTS)
  924 FORMAT('+',11X,13(I8,1X))
      WRITE(6,925)
  925 FORMAT(1X,'IN 2ML SW')
      WRITE(6,926)
  926 FORMAT(//,1X,'UNCERT(+)')
      WRITE(6,931)
  931 FORMAT('+',7X,'_')
      WRITE(6,930) (BSUM(I),I=1,NUMPTS)
  930 FORMAT('+',13X,13(I6,3X))
      CALL PLOTIT(DEPTH,NUMPTS,STAT)
      CALL PLOTWO(DEPTH,PART,NUMPTS,STAT)
      GO TO 15
  915 STOP
      END
```

Program producing Data Table printout.

```
      SUBROUTINE VOLCAL(PART,SUM,NUMPTS,BSUM)
      COMMON VOLCH(13,14)
      INTEGER PART,SUM ,VOLCH
      INTEGER BSUM,UNCERT
      DIMENSION BSUM(13),UNCERT(13,14)
      DIMENSION PART(13,14),SUM(13)
      DO 778 I=1,NUMPTS
      VOL=1.39463
      SSUM=0
      USUM=0
      DO 777 J=1,14
      UNCERT(I,J)=PART(I,J)**.5*VOL
      VOLCH(I,J)=PART(I,J)*VOL
      VOL=VOL*2.0
      USUM=USUM+UNCERT(I,J)
  777 SSUM=SSUM+VOLCH(I,J)
      SUM(I)=SSUM
      BSUM(I)=USUM
  778 CONTINUE
      RETURN
      END
```

Subroutine for calculating UNCERTINITY factor.

```
      SUBROUTINE PLOTWO(DEPTH,PART,NUMPTS,STAT)
      DIMENSION DEPTH(13),DDIA(14),DDIAL(14),ZTEMP(14),PART(13,14),
     1PARTLG(13,14)
      INTEGER DEPTH,PART,STAT
      DIMENSION XTITLE(4),YTITLE(9)
      DATA DDIA/1.37,1.73,2.18,2.74,3.46,4.36,5.49,6.92,8.71,10.98,
     113.83,17.43,21.96,27.66/
      DATA XTITLE/'LOG ','OF D','IAME','TER '/
      DATA YTITLE/'LOG ','OF P','ARTI','CLE ','COUN','T/CH','ANNE',
     1'L/DE','PTH '/
      DO 254 I=1,NUMPTS
      DO 251 J=1,14
      DDIAL(J)=ALOG10(DDIA(J))*4.
      IF(PART(I,J).NE.0)GO TO 275
      PARTLG(I,J)=0.0
      GO TO 254
  275 PARTLG(I,J)=ALOG10(FLOAT(PART(I,J)))
  251 CONTINUE
  254 CONTINUE
      CALL PLOTS
      CALL AXIS (0.5,0.0,XTITLE,-15,5.5,0.0,.125,0.25)
      CALL AXIS (0.5,0.0,YTITLE,28,7.0,90.0,0.0,1.0)
      DO 252 I=1,NUMPTS
      DO 253 J=1,14
      ZTEMP(J)=(PARTLG(I,J))
  253 CONTINUE
      NSYM=MOD(I,7)+1
      CALL LINE (DDIAL,ZTEMP,14,1,NSYM)
  252 CONTINUE
      CALL SYMBOL(0.0,8.00,0.14,'L.DIDDLEMEYER',0.0,13)
      CALL SYMBOL(0.0,7.5,0.14,'STATION NO.',0.0,11)
      CALL SYMBOL(1.5,7.5,0.14,STAT,0.0,4)
      CALL PLOT(0.0,11.0,-3)
      CALL PLOTE
      RETURN
      END
```

Subroutine for plotting Type 1, Type 2, and Type 5 graphs

```
      DIMENSION RDEPTH(9)
      DIMENSION DDIA(14),LABEL(20),COUNTL(14,9)
      DIMENSION WK(14,9,3),KX(500),KY(500)
      INTEGER*4 COUNT(14,9),DEPTH(9)
      REAL*8 TTL(12)/'PARTICLE',' COUNT V','S PARTIC','LE DIAME','TER VS
     *  ','        ','STATION ','NUMBER  ','        ','        ',
     *'LINE I 1','0 METERS'/
      LOGICAL*1 IDN(14,9)
      REAL*4 F(2)/0.0,0.0/
      REAL*4 SIZE(2)/2*6./
      DATA DDIA/13.7,17.3,21.8,27.4,34.6,43.6,54.9,69.2,87.1,109.8,
     *138.3,174.3,219.6,276.6/
      DATA LINES/0/
      DATA ALPHA,BETA/15.0,45.0/
      DATA NROW,NCOL/14,9/
      DATA NKXY/500/
      READ(5,100) NDEPTH
  100 FORMAT(I2)
      DO 500 J=1,NDEPTH
      READ(5,200) DEPTH(J),(COUNT(I,J),I=1,8)
  200 FORMAT (5X,I4,8X,8(I6,1X))
      READ(5,300) (COUNT(I,J),I=9,14)
  300 FORMAT (17X,6(I6,1X))
  500 CONTINUE
      READ(5,600) (LABEL(I),I=1,20)
  600 FORMAT(20A4)
      DO 800 J=1,NDEPTH
      DO 700 I=1,14
      IF (COUNT(I,J).NE.0) GO TO 400
      COUNTL(I,J)=0.0
      GO TO 700
  400 COUNTL(I,J)=ALOG10(FLOAT(COUNT(I,J)))*100.
  700 CONTINUE
      RDEPTH(J)=FLOAT(DEPTH(J))*20.
  800 CONTINUE
      CALL PLT3D1(DDIA,NROW,RDEPTH,NCOL,COUNTL,ALPHA,BETA,F,TTL,SIZE,
     *WK,IDN,KX,KY,NKXY,LINES)
      STOP
      END
```

Program for plotting Type 3 and Type 4 graphs

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